Evidence for Single Top Production at CDF

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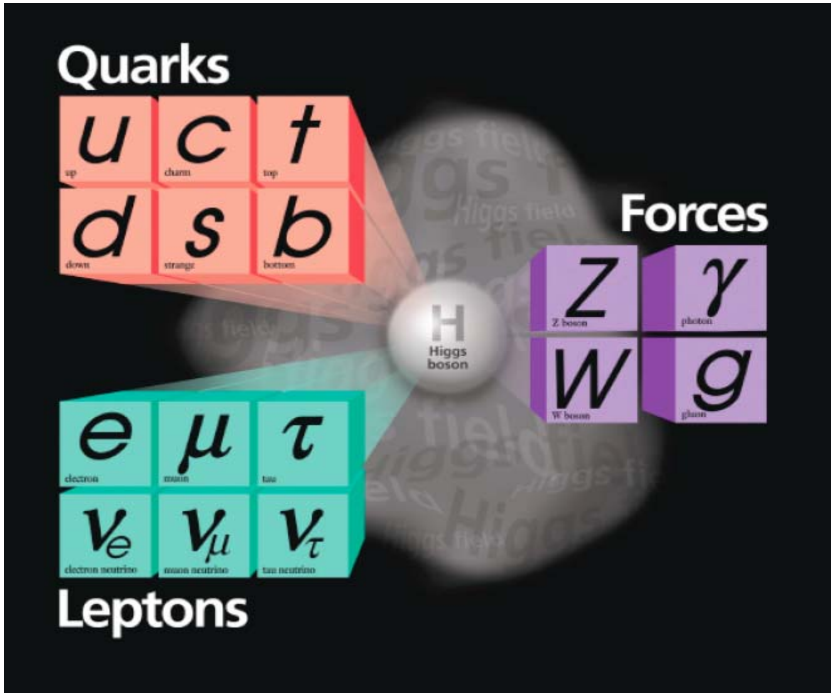
- Motivation for the Search
- Detector Apparatus
- Search Strategies
  - Likelihood Function
  - Matrix Element
- Results
- Future Plans

The Standard Model Works Too Well (and not Well Enough)

- Accounts for observed collider results
- Electroweak gauge symmetry very powerful at predicting QED and Weak interaction results to many significant digits.



But: There are significant missing pieces
1) What beaks SU(2)xU(1) EW symmetry? Is it minimal, or something more exciting?
2) What is dark matter?
3) What is dark energy?

And some unanswered questions:
1) Why three generations?
2) Are there three generations?
3) What stabilizes m_H against radiative corrections?
4) Why are neutrino masses so small?

Belief in the Standard Model is nearly universal, but we all know it is incomplete.

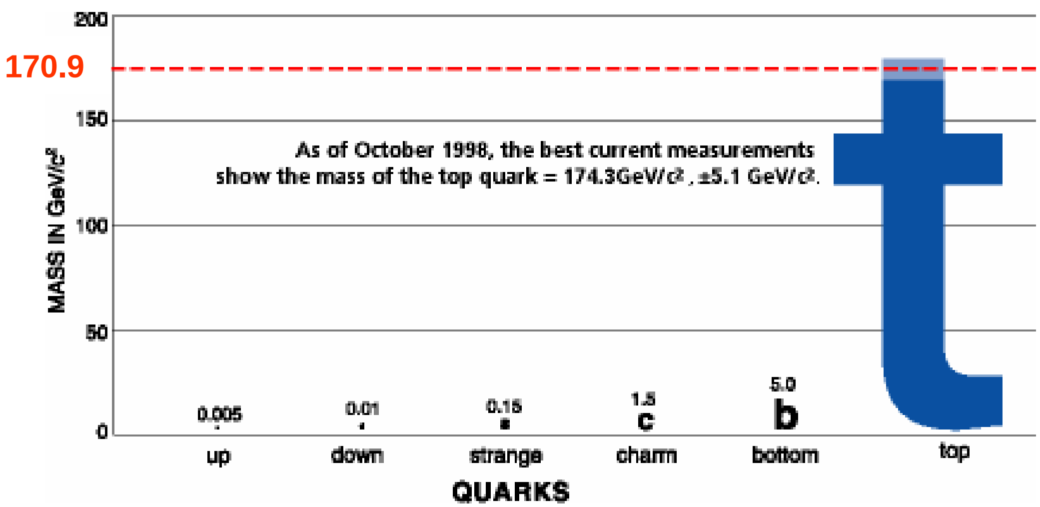
Is the Top Quark Trying To Tell Us Something?

- Heaviest fundamental fermion known so far **m_t =170.9 +- 1.8 GeV/c^2**

- Yukawa coupling ~1
- Why is top so heavy? Possibly better question: Why are the other fermions so light? Top could be the only "natural" fermion.

- Alternative Higgs model – t-tbar condensate?

- One of the main ingredients of the radiative corrections to m_H is the top loop

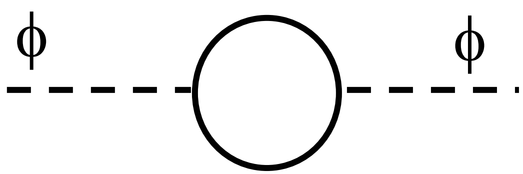


Stability of Higgs Boson Mass under Radiative Corrections

Higgs particles exquisitely sensitive to new, heavy particles.

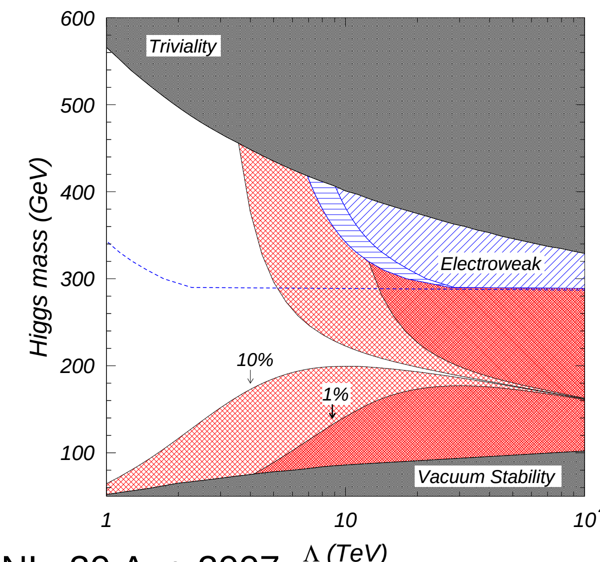
We don't yet know what happens at the Planck scale:

$$m_{pl} = \sqrt{\hbar c / G_N} \approx 1.2 \times 10^{19} \text{ GeV}$$



If no new physics below a scale of Λ, Higgs mass gets big corrections from Loops involving SM particles

$$\delta m_h^2 \propto \frac{\Lambda^2}{v^2}\left(2m_W^2 + m_Z^2 + m_h^2 - 4m_t^2\right)$$



"Unnatural" to have $\delta m_h >> m_h$

Kolda and Murayama, hep-ph/0003170

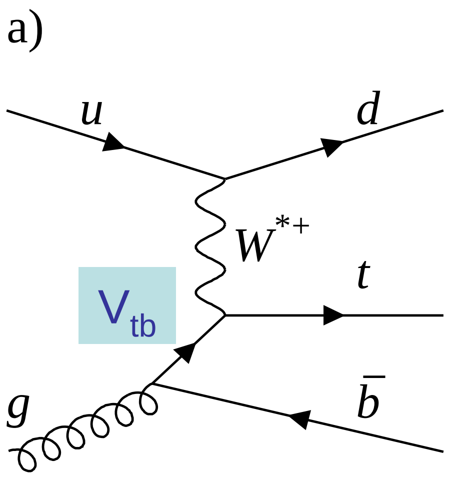
Theoretical Motivation for Searching for Single Top

1) Production rate is proportional to $|Vtb|^2$

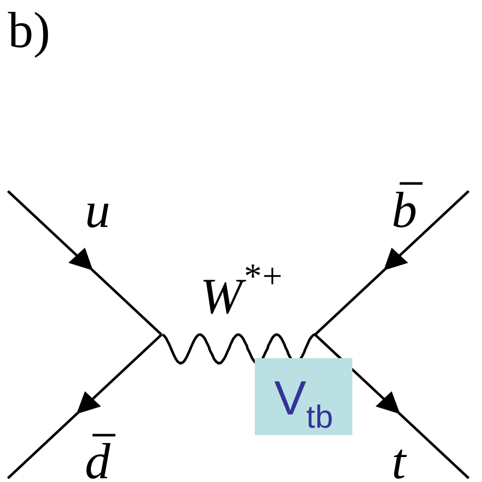
$$\sigma_s = (0.88 \pm 0.11)\,|V_{tb}|^2 \text{ pb}$$

$$\sigma_t = (1.98 \pm 0.25)\,|V_{tb}|^2 \text{ pb}$$

B.W. Harris et al., Phys. Rev. D66, 054024 (2002).
Z. Sullivan, Phys. Rev. D70, 114012 (2004).
Compatible Results;
Campbell/Ellis/Tramontano, Phys. Rev. D70, 094012 (2004).
N. Kidonakis, Phys. Rev. D74, 114012 (2006).



t-channel production



s-channel production

Other production modes are small at the Tevatron collision energy:

$$g + b \rightarrow W^- + t$$ W-strahlung

$$g + u \rightarrow t + \overline{b} + d$$ Looks like *s*-channel but overlaps *t*-channel's phase space

Interest in $|V_{tb}|$

From the PDG review 2006 (Ceccucci, Ligeti, Sakai)

$$V_{\mathrm{CKM}} \equiv V_L^u V_L^{d\dagger} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

$$V_{\mathrm{CKM}} = \begin{pmatrix} 0.97383^{+0.00024}_{-0.00023} & 0.2272^{+0.0010}_{-0.0010} & (3.96^{+0.09}_{-0.09}) \times 10^{-3} \\ 0.2271^{+0.0010}_{-0.0010} & 0.97296^{+0.00024}_{-0.00024} & (42.21^{+0.10}_{-0.80}) \times 10^{-3} \\ (8.14^{+0.32}_{-0.64}) \times 10^{-3} & (41.61^{+0.12}_{-0.78}) \times 10^{-3} & 0.999100^{+0.000034}_{-0.000004} \end{pmatrix}$$

- Magnitudes only
- 3x3 Unitarity enforced

But what if there's a fourth generation? (needs a corresponding heavy neutrino, and m_H cannot be close to 160 GeV)

$$V_{CKM} = \begin{vmatrix} V_{ud} & V_{us} & V_{ub} & V_{uX}\,? \\ V_{cd} & V_{cs} & V_{cb} & V_{cX}\,? \\ V_{td} & V_{ts} & V_{tb} & V_{tX}\,? \\ V_{Yd}\,? & V_{Ys}\,? & V_{Yb}\,? & V_{YX}\,? \end{vmatrix}$$

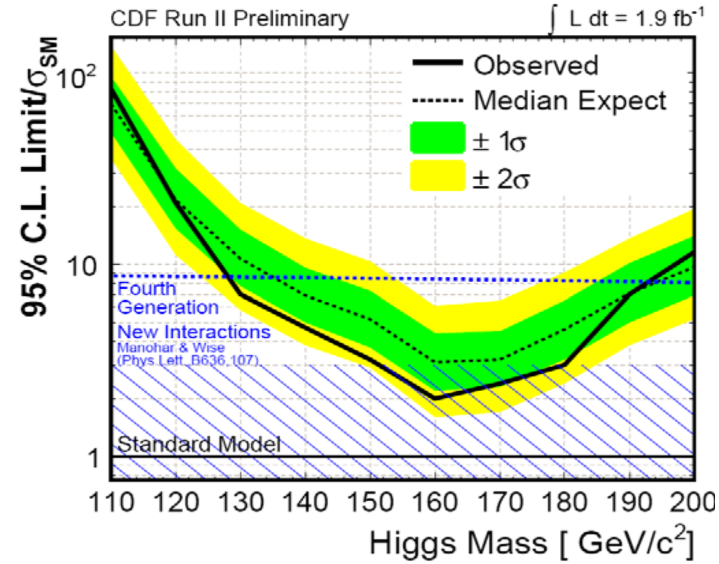
Precision EW rules out "simple" fourth generation extensions, but see

J. Alwall et. al., "Is $|V_{tb}|$~1?" Eur. Phys. J. C49 791-801 (2007).

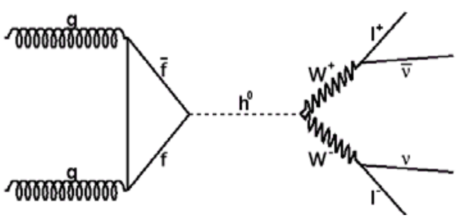
It's Not Looking Good For a Fourth Generation, However!

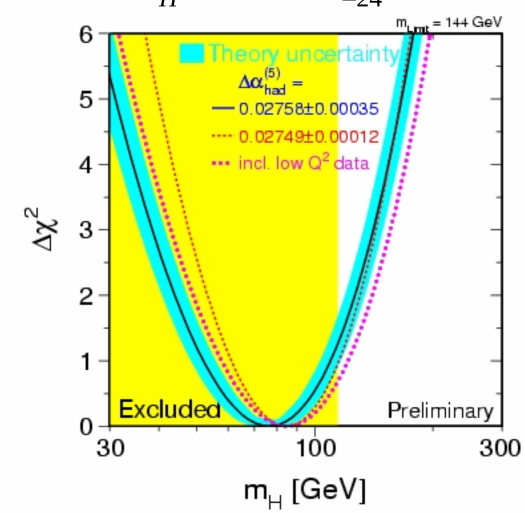
Higgs production via gluon-gluon fusion proceeds mostly via a top loop in a 3-gen model, and gets a boost from heavier quarks if they exist.

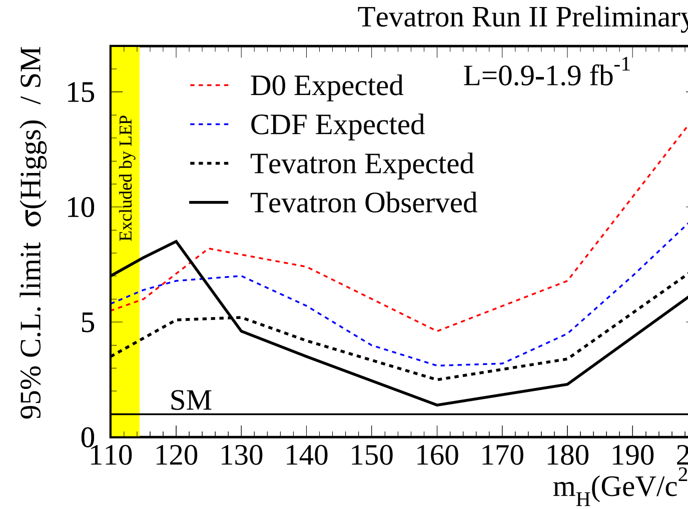
Propagators and vertex mass dependencies cancel in the triangle diagram.



$$m_H^{EW-fit} = 76^{+33}_{-24}\ \text{GeV}$$







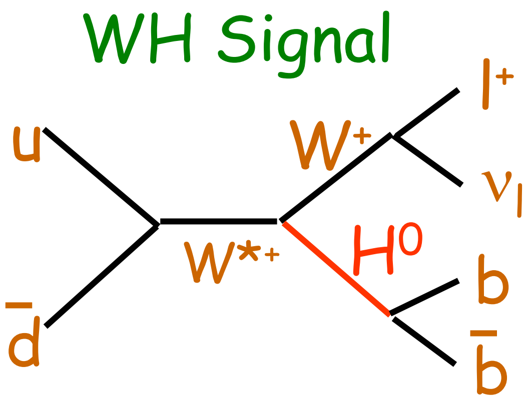
Argument depends on SM assumptions – new physics could allow a Fourth Generation

Additional Motivations for Seeking Single Top

- It's a background to WH→lvbb – let's measure it instead of relying on MC.
- Its backgrounds are backgrounds to WH→lvbb (W+jets, ttbar, QCD, dibosons)
- It has a larger cross section than WH→lvbb (order of magnitude)
- The kinematic signature is more distinct than WH→lvbb
  - We know what we're looking for (m_H is unknown, but m_t is known)
  - Top quarks stick out experimentally – large event energies
  - Top quarks are polarized in single-top production due to the V-A interaction at the production vertex
    Polarization is not diluted by hadronization: Top quarks decay before they can hadronize, and their decay products retain polarization information (not so for B mesons).
- It's a great testing ground for making a discovery using advanced signal/background separation techniques!
- A check of the b PDF of the proton
- Can search for FCNC's involving top quarks
- Can search for heavy W′ bosons (L or R-handed), contributing to s-channel t production.

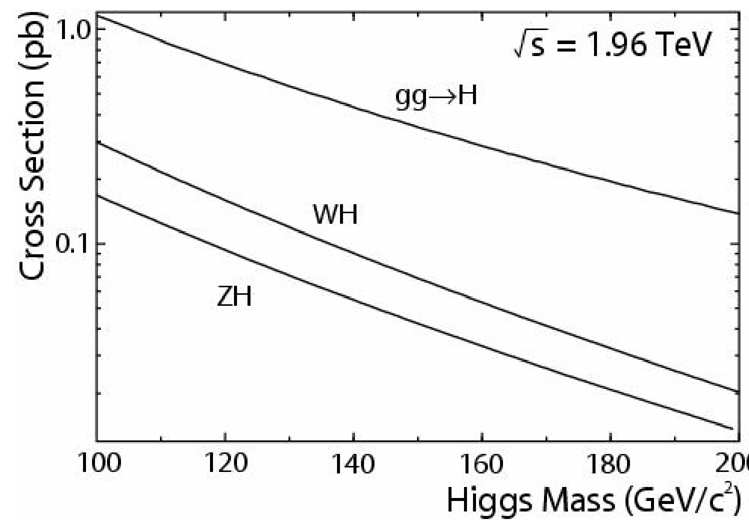
Single-Top and WH! lν bb Signals

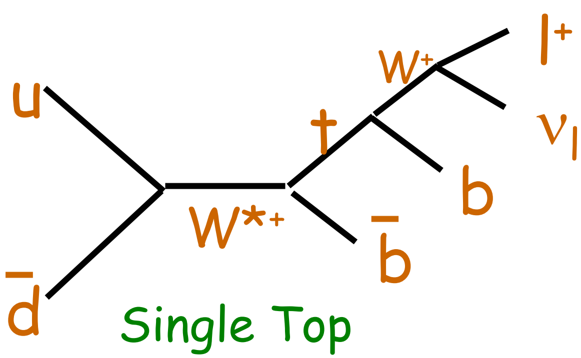
Same Final state – Overlapping kinematics



~200 fb

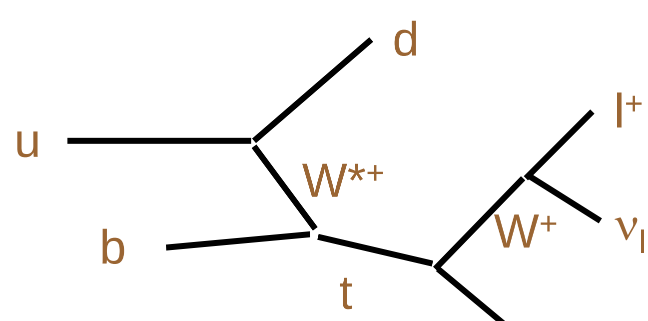
SM Higgs cross sections @NLO
(we know better now…)





s-channel

0.88 pb

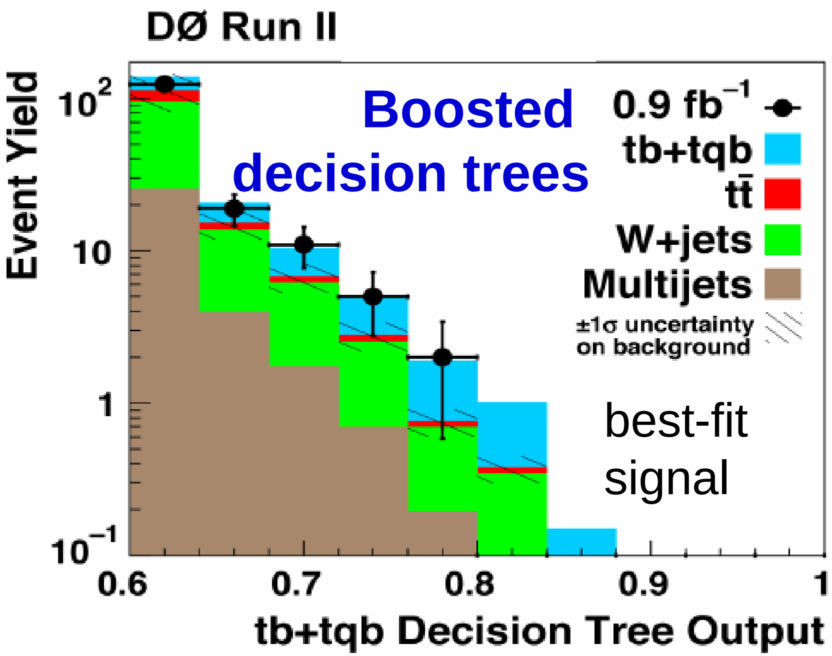


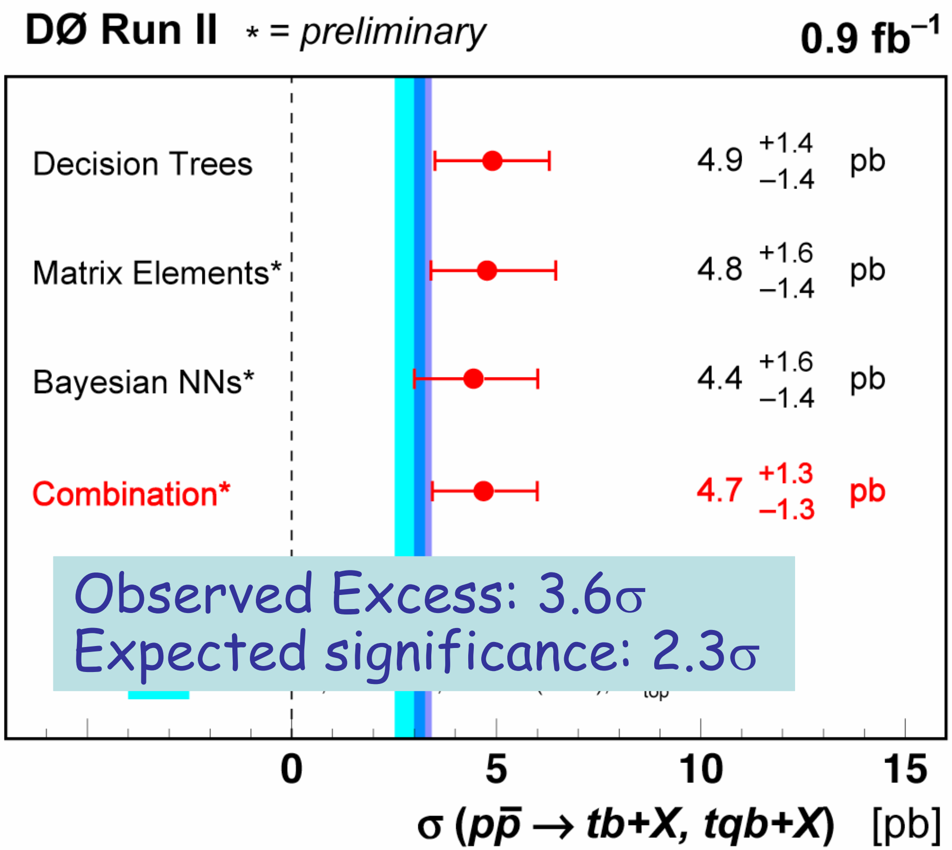
t-channel

slightly different
-- just one b
here

1.98 pb

DØ Claimed Evidence for Single Top in November 2006





Observed Excess: 3.4σ
Expected sensitivity: 2.1σ

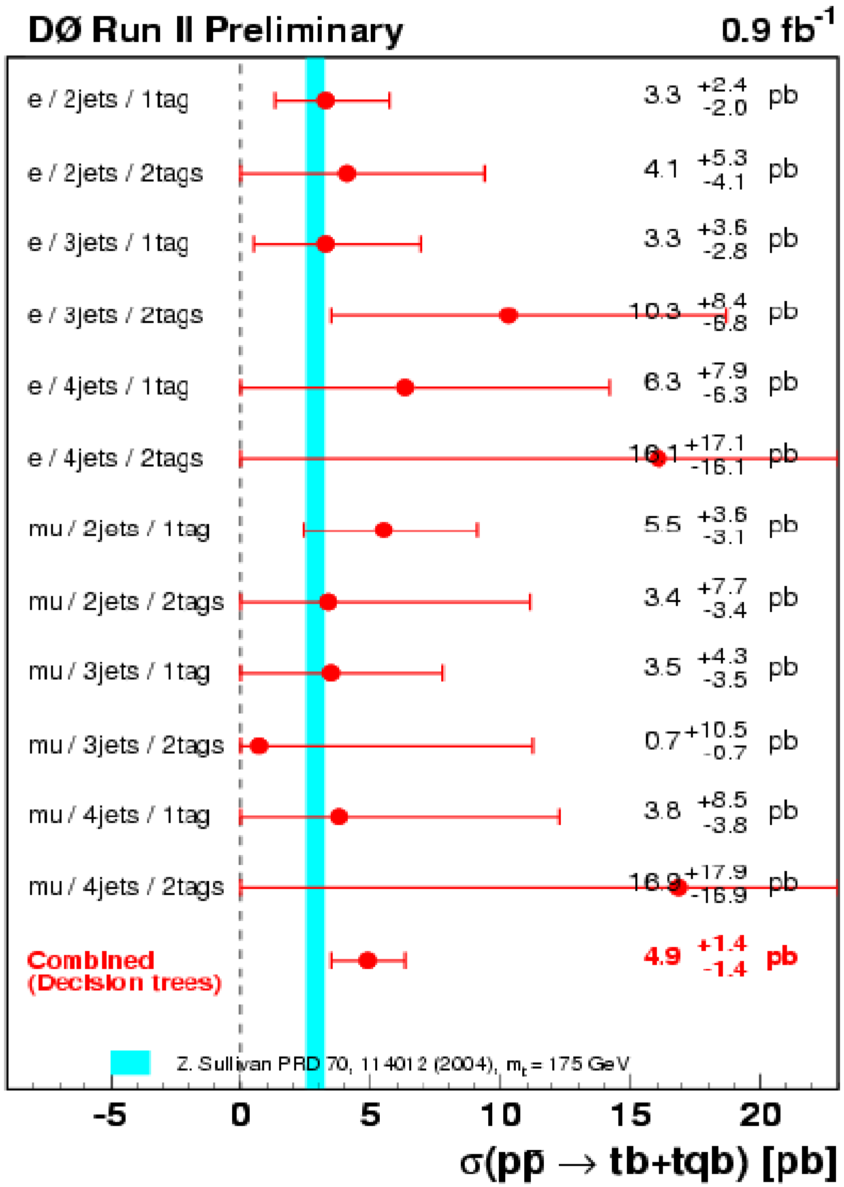
σ_{s+t}= 4.9 ±1.4 pb

σ_s= 1.0, σ_t =4.0 pb

PRL 98 18102 (2007)

First direct measurement of V_{tb}:
0.68 <$|V_{tb}|$< 1 @ 95%CL or
$|V_{tb}|$ = 1.3 ± 0.2

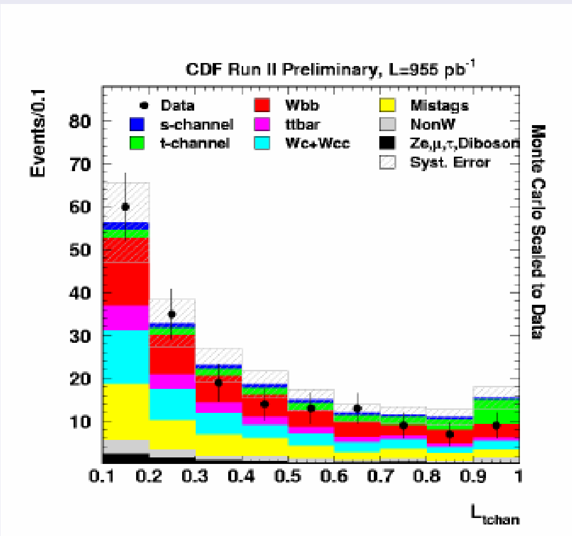
DØ Got Lucky in 1 fb^{-1}



Decision Tree Analysis – 11/12 measurements in excess of SM prediction

CDF Got Unlucky in 1 fb^{-1}

Likelihood

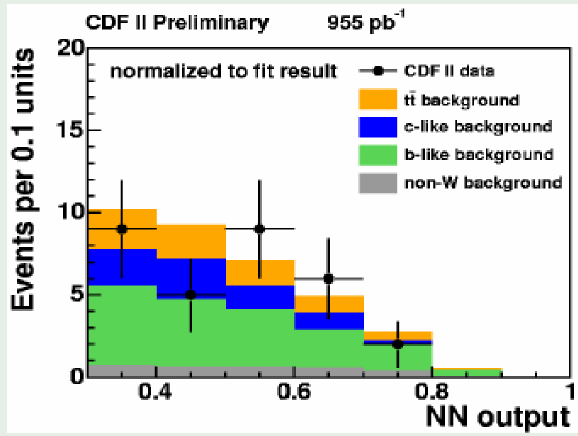


No evidence of signal

$\sigma < 2.7$ pb @ 95% CL

From s and t likelihoods

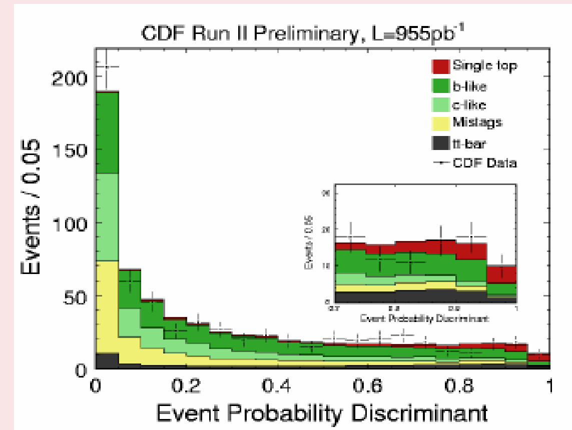
Neural network



no evidence of signal

$\sigma < 2.6$ pb @ 95% CL

Matrix element



$\sigma = 2.7^{+1.5}_{-1.3}$ pb

p-value = 1.0% (2.3σ)

Also results have low consistency – 5% level for LF/ME, 1% for NN/ME.

Fermilab from the Air

Tevatron
ring radius=1 km

Protons on
antiprotons

$$\sqrt{s_{p\bar{p}}} = 1.96 \text{ TeV}$$

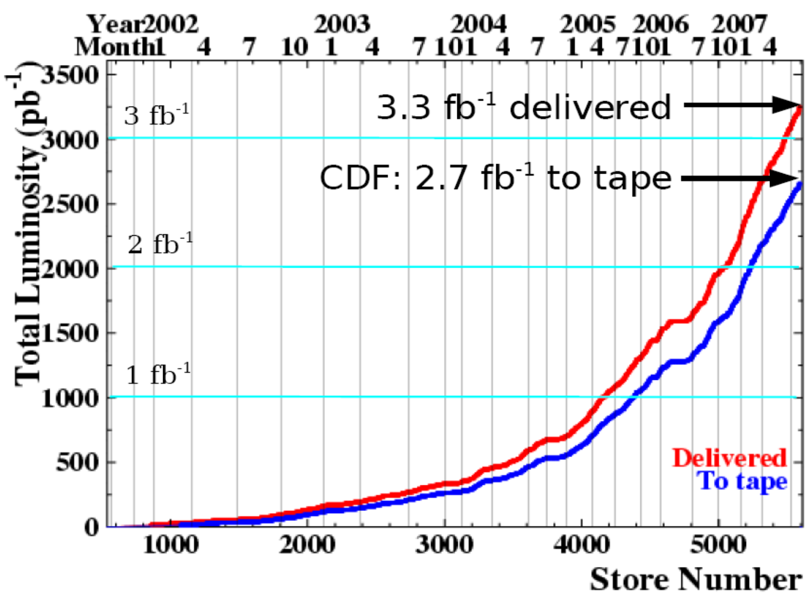
Main Injector
commissioned in 2002

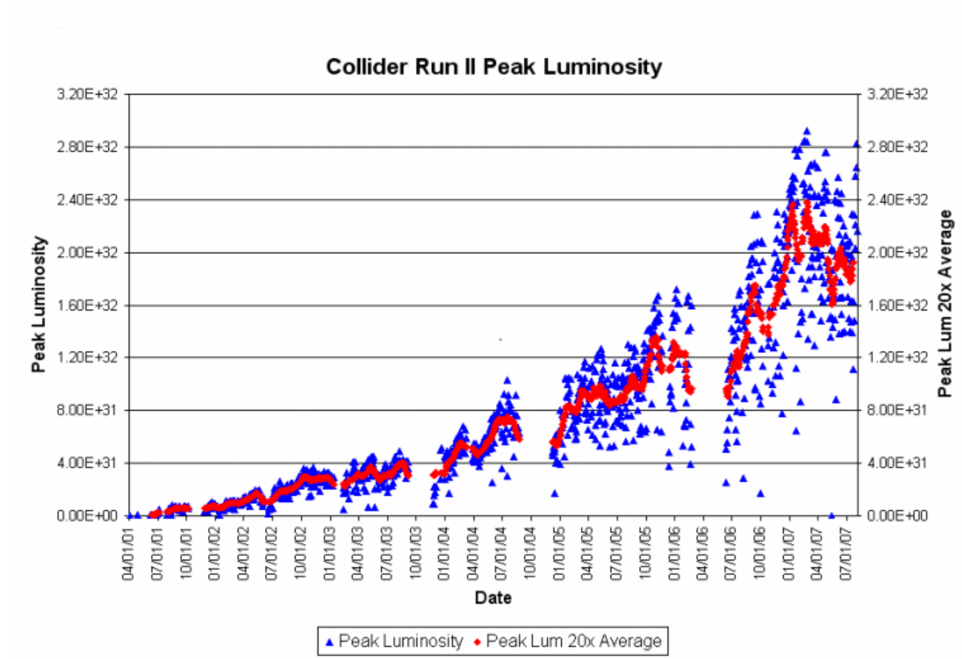
Recycler used
as another antiproton
accumulator

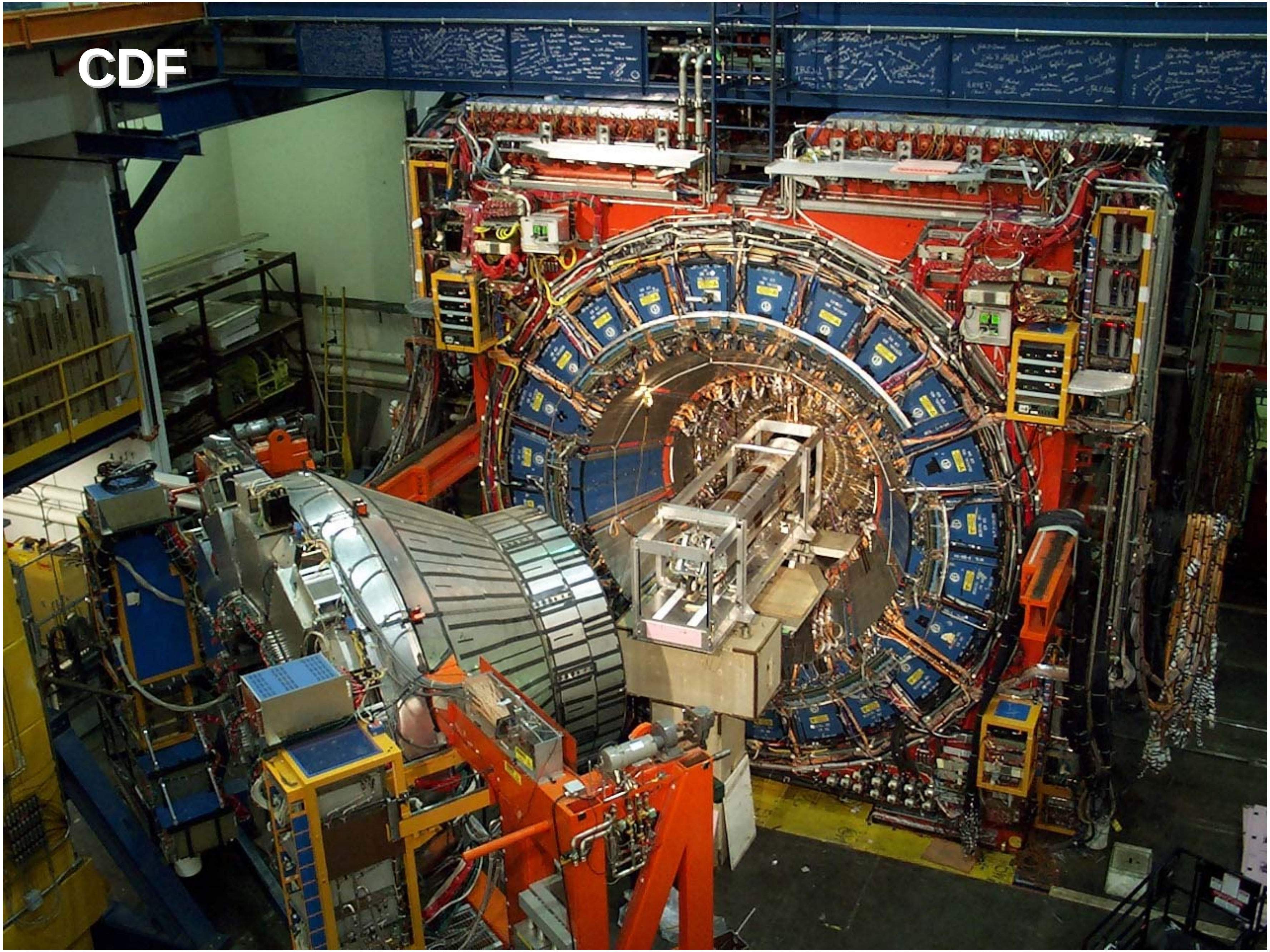
Start-of-store luminosities
exceeding 200×10^{30} now
are routine

Tevatron Run II Luminosity Performance

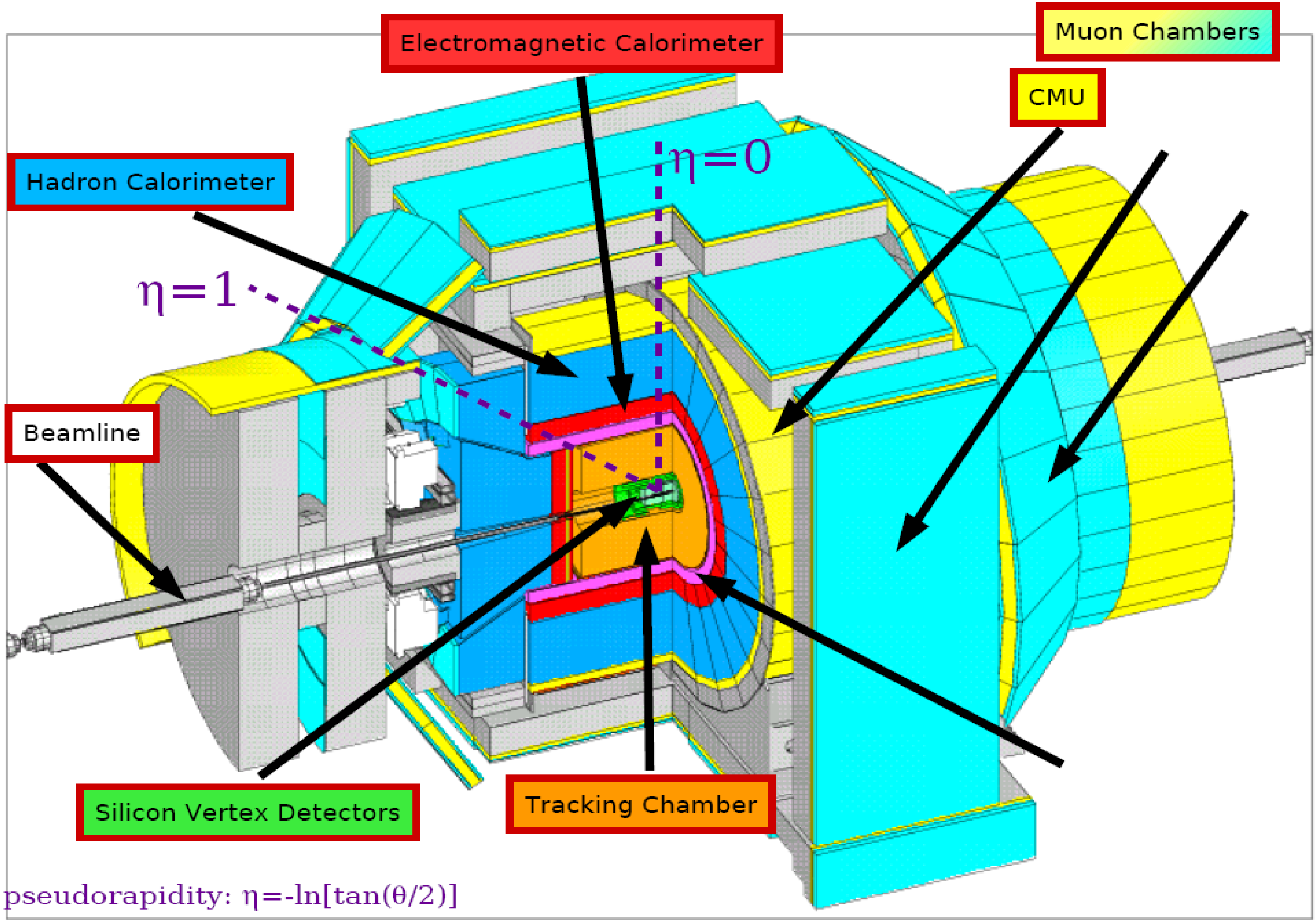
- Off to a slow start in 2002
- Many improvements made over the years:
  - Increased antiproton production and cooling (e-beam cooling commissioned in 2006). Recycler re-purposed as a pbar accumulator
  - Improved reliability and turnaround, fewer injection losses
  - Tevatron magnets aligned, collision point optics optimized






CDF

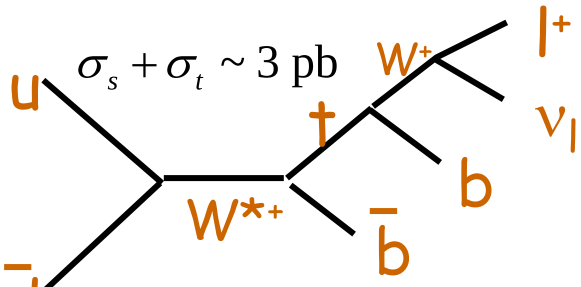
CDF


Electromagnetic Calorimeter
Muon Chambers
CMU
Hadron Calorimeter
η=0
η=1
Beamline
Silicon Vertex Detectors
Tracking Chamber
pseudorapidity: η=-ln[tan(θ/2)]

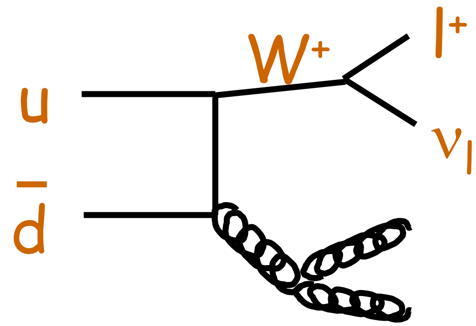
Signal and Background Summary

Not all diagrams shown.

$\sigma_s + \sigma_t \sim 3$ pb

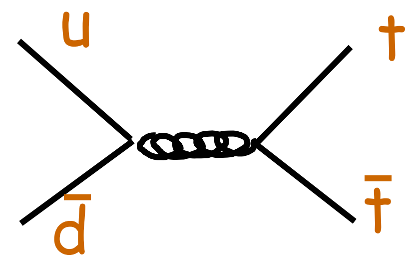


Single Top (s)

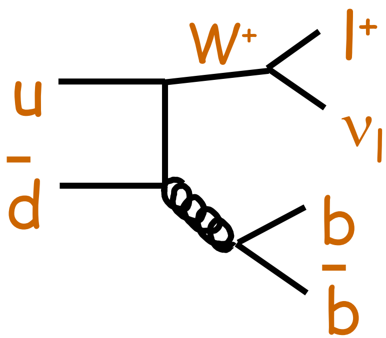


"W2p"
Need
one false
b-tag

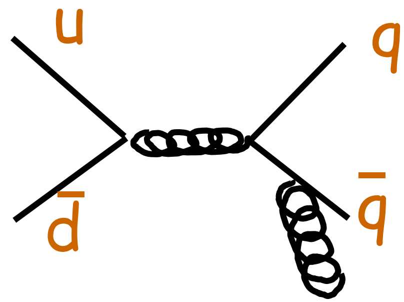
$\sigma \sim 6.5$ pb



"ttbar":
Jets+leptons
from W decay
(also t-chan)



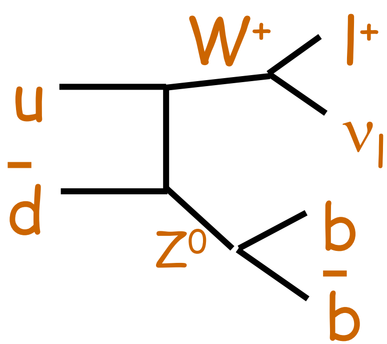
Large
background
(also Wc$\bar{c}$
and W+c)



"Non-W"

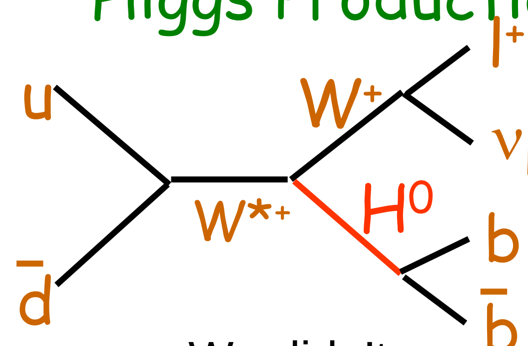
$\sigma \sim ??$ pb

Must measure as many of these with data as possible!



"Diboson"

Higgs Production

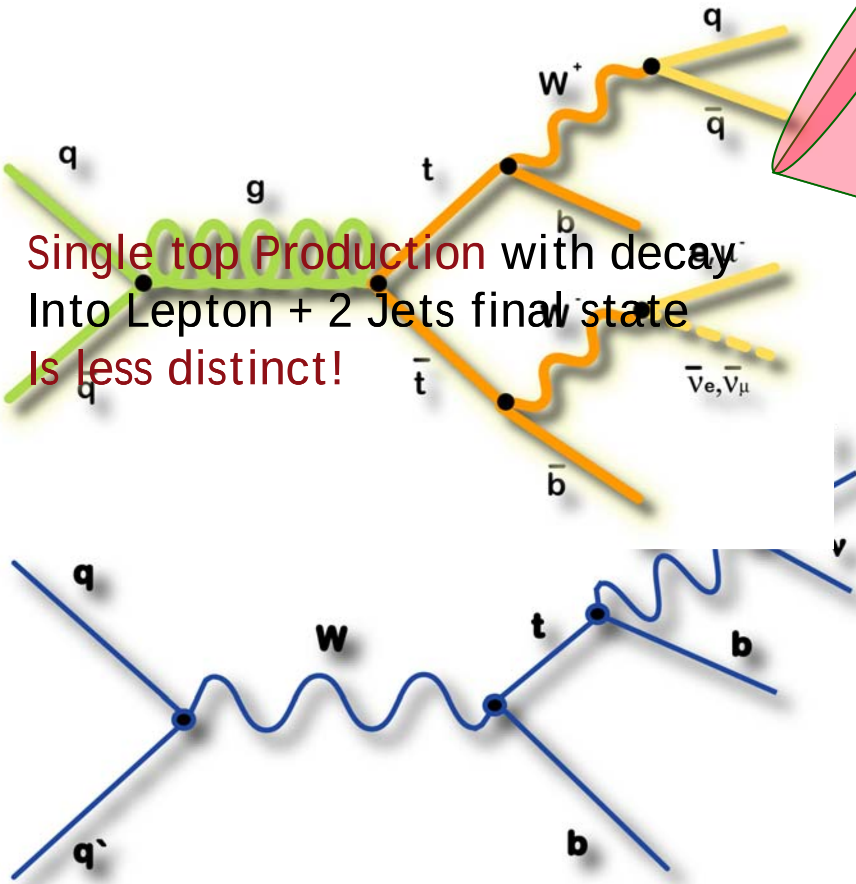


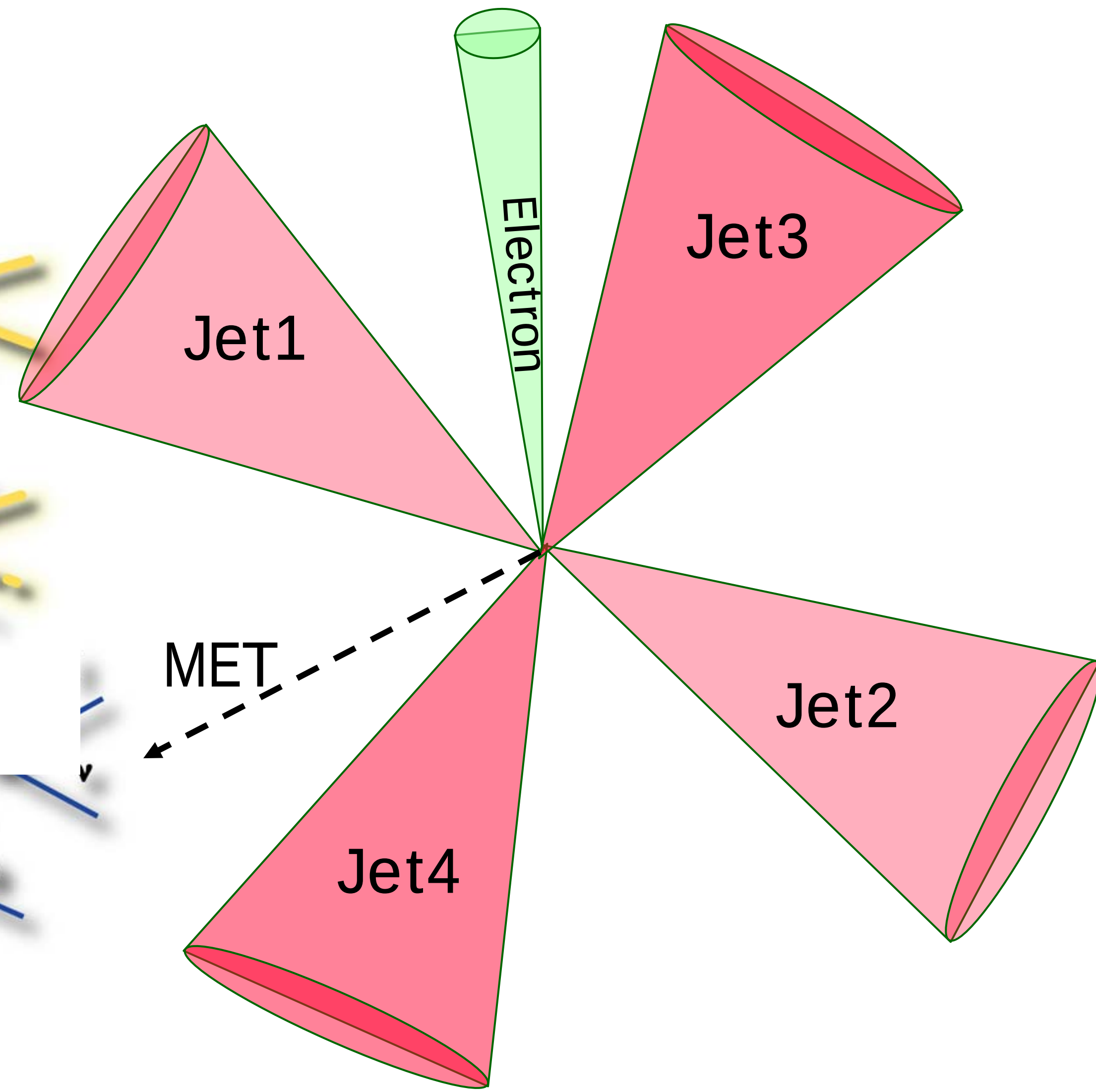
We didn't include this one

Experimental Signatures

Top Pair Production with decay
Into Lepton + 4 Jets final state
are very striking signatures!

Single top Production with decay
Into Lepton + 2 Jets final state
Is less distinct!

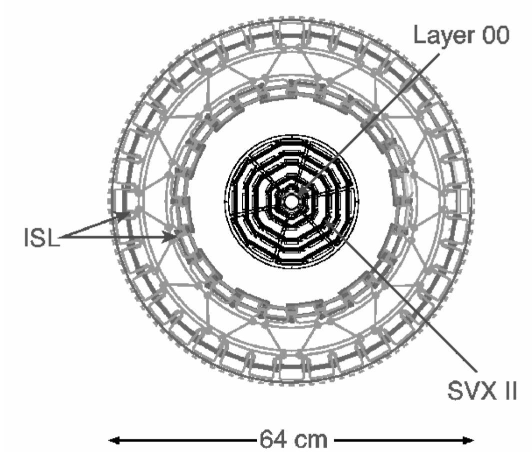




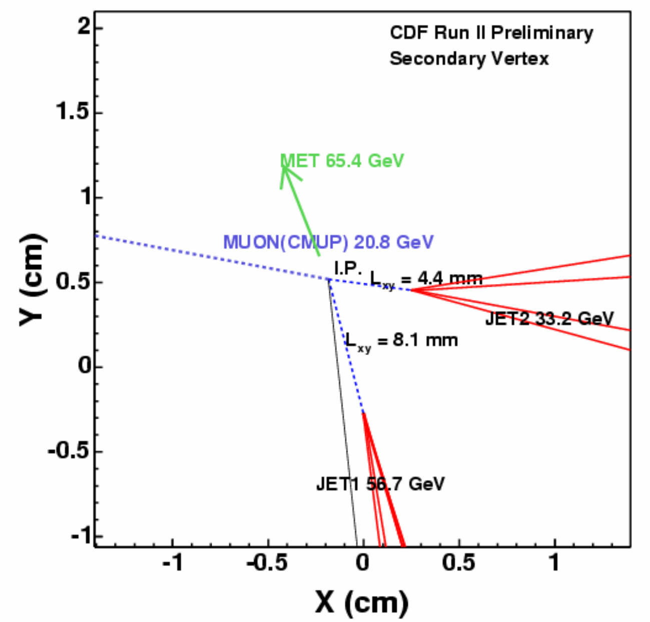
Animation courtesy of B. Stelzer

B-Tagging at CDF

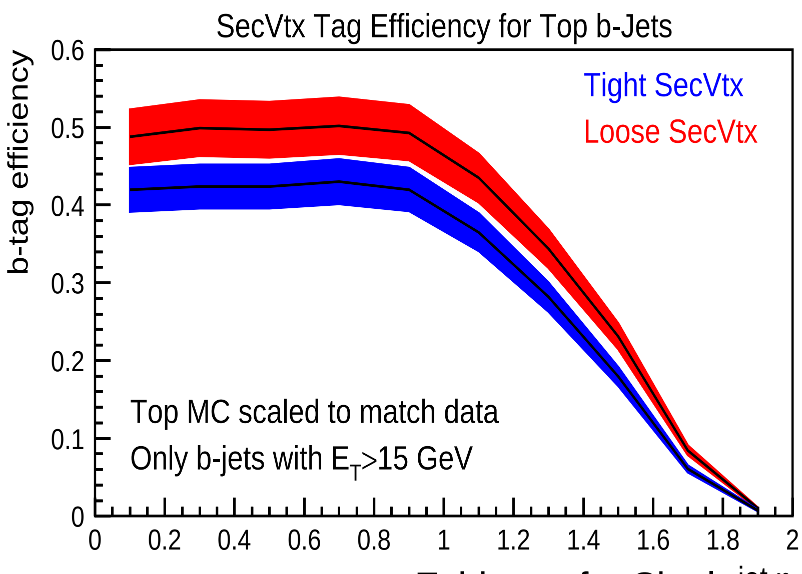
L00 single-sided silicon +
5-layer double-sided silicon+
2-layer ISL



Impact parameter resolution for high-p_T tracks ~18μm



B-tagging relies on displaced vertex reconstruction



Mistag rates typically 0.5% for light-flavor jets

Example candidate event

A Neural-Net B-tagging Tool

Identified secondary-vertex tags have a significant charm and mistag contamination.

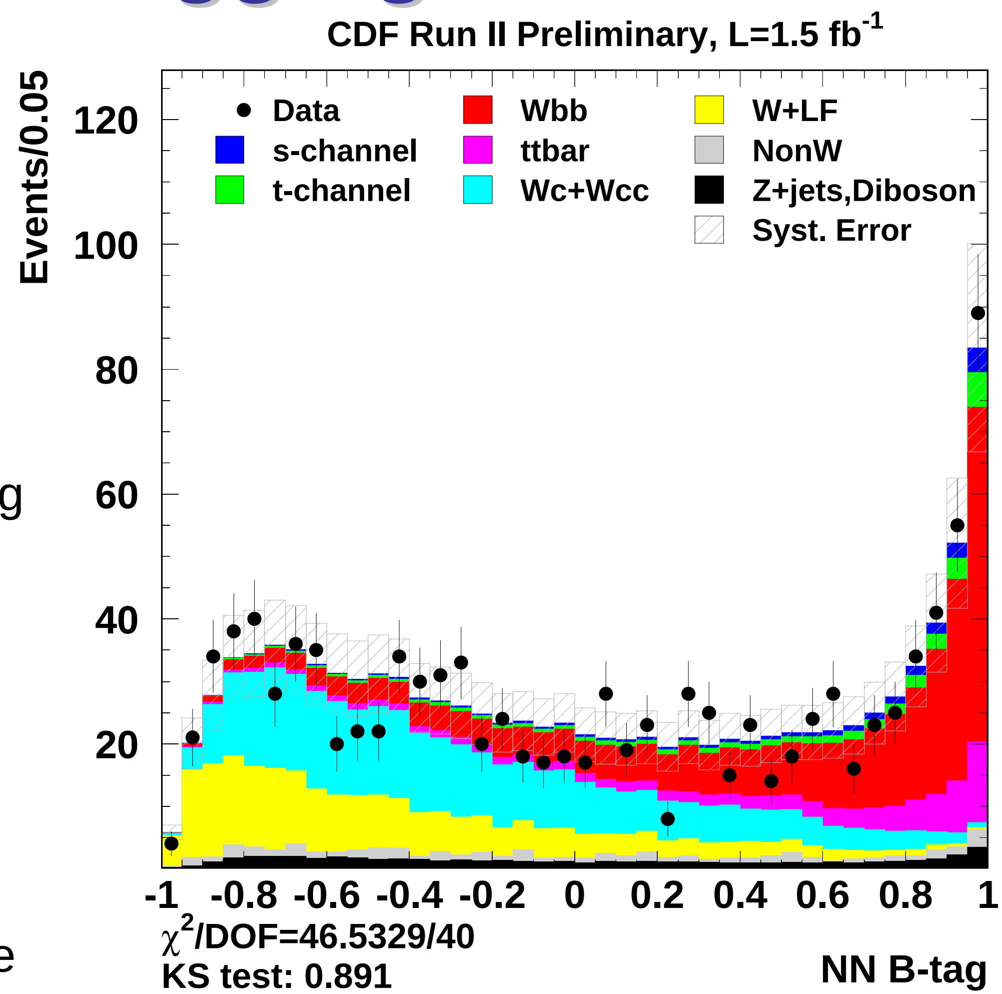
Can adjust the operating point for more purity, but at a loss of efficiency.

Events can be close to cuts if operating point is tight.

➔Train a NN to separate b, c, LF in the vertex-tagged samples.

Inputs:

- # tracks in displaced vertex
- Decay flight distance and significance
- Identified leptons in and near jets
- Secondary vertex fit χ^2
- Jet E_T (actually events out biases)

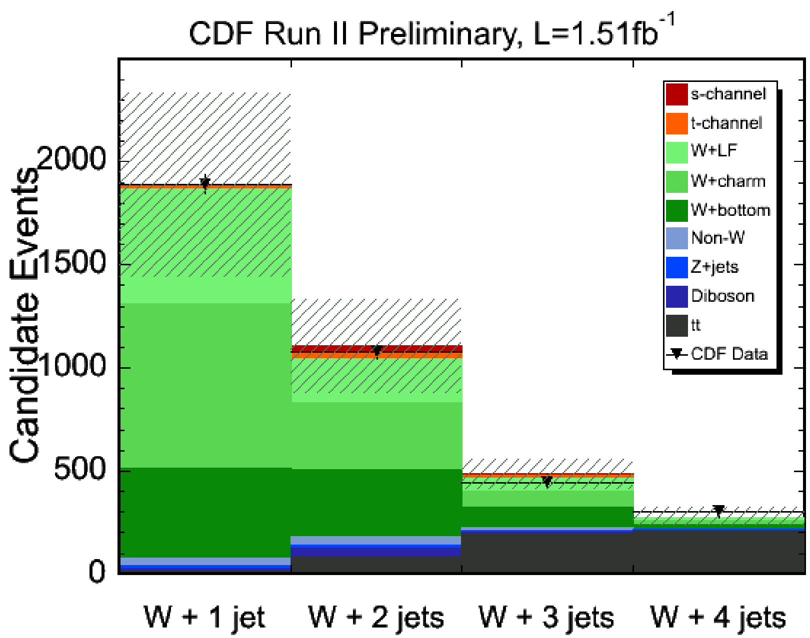


Very powerful at separating out residual mistags and charm from b-tagged sample

Preselection and Yields

- 2 jets, E_t>20 GeV each, corrected to hadron level; One jet b-tagged
- Missing E_t>25 GeV
- One lepton (e or μ), E_t>20 GeV. Isolated from other calorimeter energy
  Energy inside a cone of R=0.4 around the lepton has to be less than
  10% of the lepton's energy
- Anti-QCD cuts – Angles between Missing E_t and jets, Missing E_t and lepton.
- Veto Dileptons (remove Z in particular), Cosmics

s-channel	23.9 ± 6.1
t-channel	37.0 ± 5.4
Single top	60.9 ± 11.5
tt	85.3 ± 17.8
Diboson	40.7 ± 4.0
Z + jets	13.8 ± 2.0
W + bottom	319.6 ± 112.3
W + charm	324.2 ± 115.8
W + light	214.6 ± 27.3
Non-*W*	44.5 ± 17.8
Total background	1042.8 ± 218.2
Total prediction	1103.7 ± 230.9
Observed	1078



A counting experiment will not work! Signal is much smaller than systematic uncertainty on the background!

Reconstruction Ambiguities

Ambiguities in the 2-jet channel

- Which jet is the b from top decay?
  t-channel signal – only one b in the detector (usually, but sometimes the other one's there) pick the b-tagged jet. Gets it right 95% of the time.
  s-channel signal – Use a linear combination of the $\Delta\chi^2$ (kinematic fit) and $Q_l \times \eta_{jet}$. Gets the b right 81% of the time.

- Quadratic ambiguity in solving for pz,v. Pick smaller |pz,v|. Gets it right 75% of the time (including cases where both pz,v solutions are the same)

Ambiguities in the 3-jet channel

Combine jets or treat separately? ISR – do not combine, FSR from b – better to combine.

Consequences of Imprecise Jet Measurement

- Lepton energy resolution is quite good $\sigma_{E_T} = 14\% / \sqrt{E_T} \oplus 1.5\%$

  for central electrons (using the electromagnetic calorimeter), and

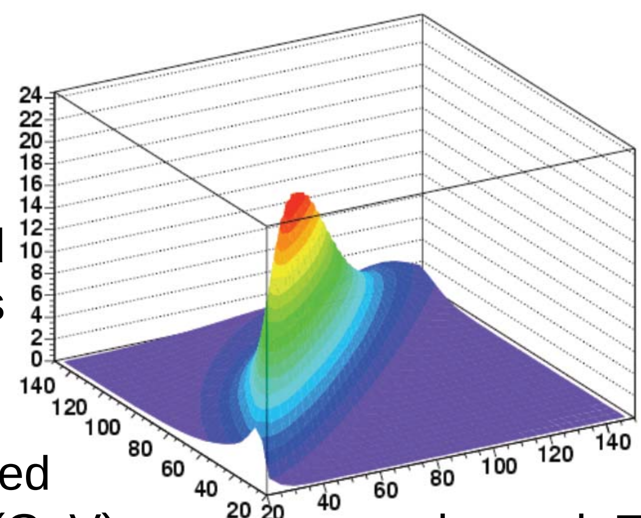
  $$\sigma(p_T)/p_T^2 = 0.0017\ c/\mathrm{GeV}$$

  for muons (using tracking chamber).

- B-jet energy is much more poorly measured. Core resolutions around 10%, but with long tails
  - >50% of b-jets have neutrinos, sometimes more than one, and sometimes very energetic.
- Badly measured b-jet energy impacts Missing-E_T measurement

- Two CDF analyses, Likelihood and Matrix Element, take different approaches to handling mismeasurement.

Fully simulated MC b-jets



Measured b-jet E (GeV)

b-quark E (GeV)

LEP-Style Likelihood Functions

- Known in the statistics business as “Naïve Bayes”
- Included in R, TMVA as options
- Very fast training, turnaround for trying out new variables, new ideas
- Sophisticated discriminant functions are only as good as their input variables
  - statistical power
  - sensitivity to systematic uncertainties
- Sensitivity to systematic mismodeling of a single input variable is usually diluted if many other strong input variables contribute

$$p_{ik} = \frac{f_{ij_ik}}{\sum_{m=1}^{5} f_{ij_ik}}$$

$$\mathcal{L}_k(\{x_i\}) = \frac{\prod_{i=1}^{n_{var}} p_{ik}}{\sum_{m=1}^{5} \prod_{i=1}^{n_{var}} p_{im}}$$

i=variable index
k=sample index (signal, Wbb, W+charm, W+LF, ttbar)
m=sum over samples
j_i=histogram bin

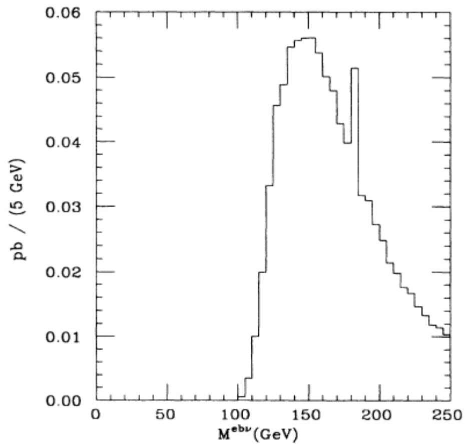
Variables used in the t-channel Likelihood Function

- H_T
- $\cos\theta_{\text{lepton, other jet}}$ in top decay frame (Mahlon and Parke; Stelzer, Sullivan and Willenbrock)
- $Q\times\eta$ (C.-P. Yuan, PRD 41 (1990) p. 42)
- M_{jj}
- $\log(ME_{t\text{-chan}})$ from MADGRAPH (Stelzer and Willenbrock)
- ANN b-tag output
- χ^2(t-channel) (replaces $m_{l\nu b}$ formerly used)

Variables require a choice of how to reconstruct the event (which jet is b, which $p_{z,\nu}$ solution), and the best measurements.

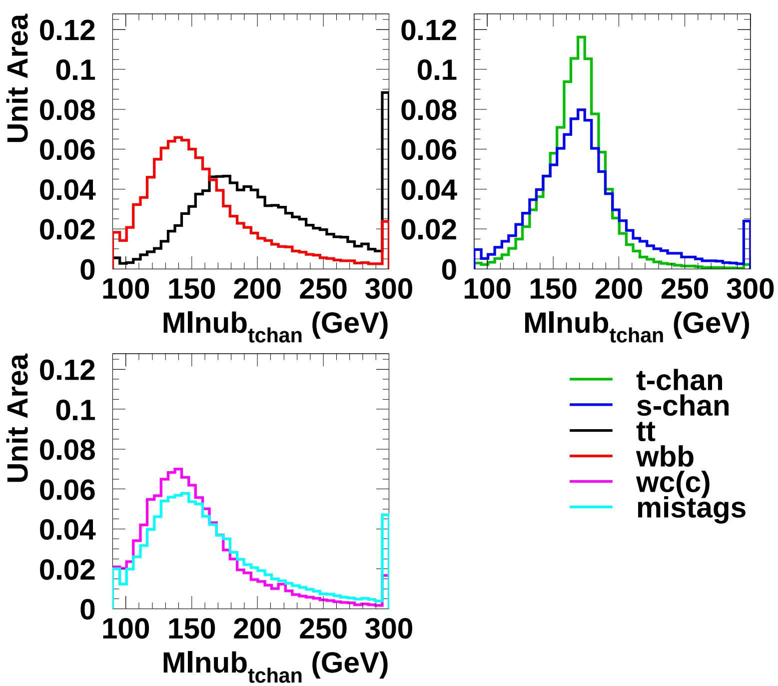
The matrix element in particular is very sensitive to ($M_{l\nu b}$-175) But the reconstructed $M_{l\nu b}$ has a broad resolution.

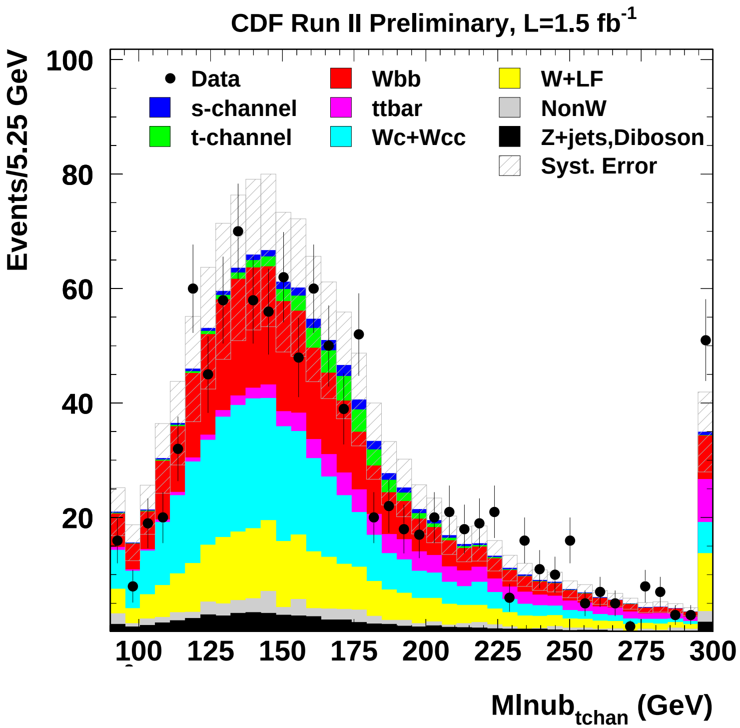
$M_{\ell\nu b}$



Yuan, 1990 (no resolution effects)

Signal and Background Templates





Kinematic Fitter and a new "Kinematic Solver"

- Constrain $M_{l\nu b}$=175 GeV, the value used in the matrix element definition
- Constrain $M_{l\nu}$=80.4 GeV, also used in matrix element definition
- Constrain lepton momentum to measured value.
- Constrain the direction of the b-jet
- Constrain p_T(top) to measured value
  - surprisingly good resolution! 10 GeV, low tails.
  - Reason: mismeasured b-jets also cause mismeasured Missing-E_T. The sum is well measured! (the other jet is not a b jet in the t-channel

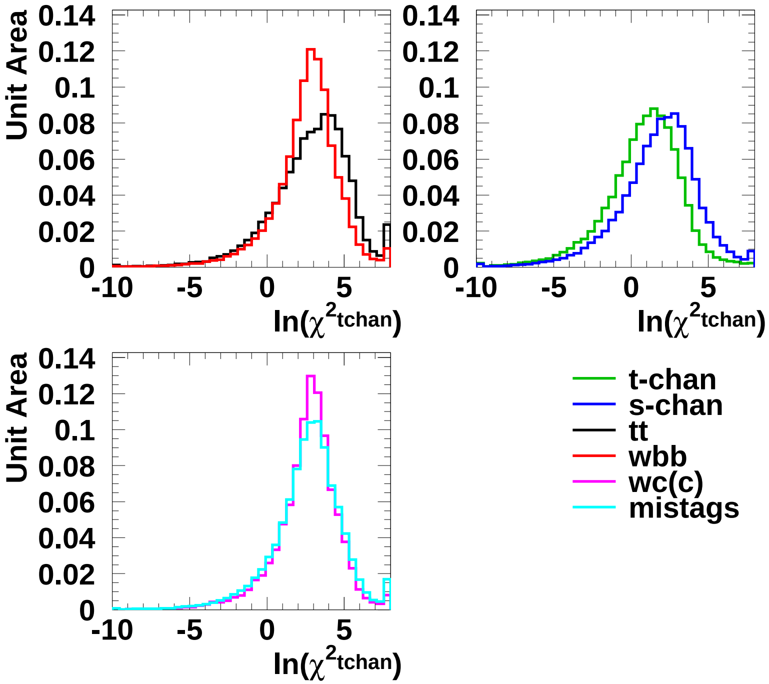
- Enough constraints there – can solve for the b-jet energy numerically More robust than a MINUIT fit

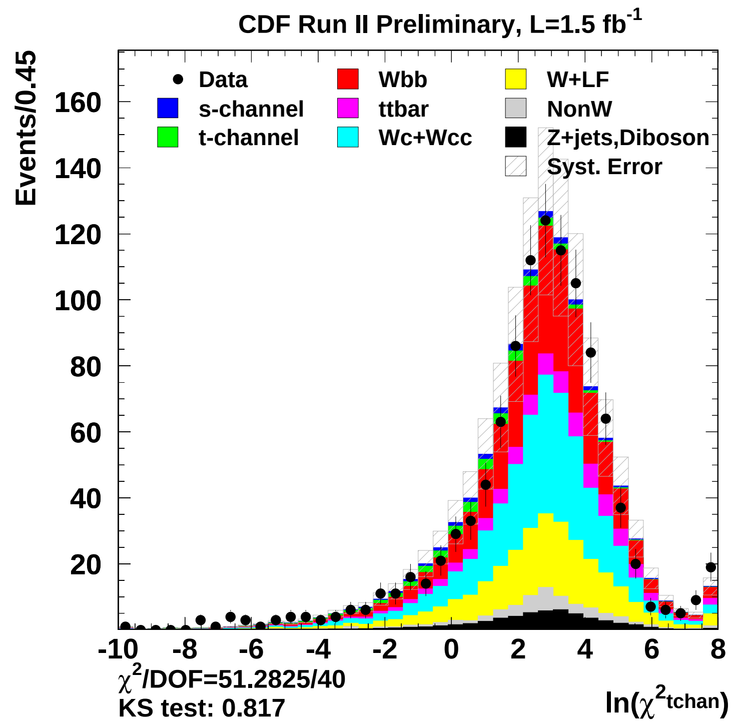
- Solution repeated for the four combinations of b choice and p_z choice.

- χ^2 of solved 4-vectors compared with measured 4-vectors used instead of $M_{l\nu b}$.

Kinematic Fit χ^2 as a Signal/Background Separator

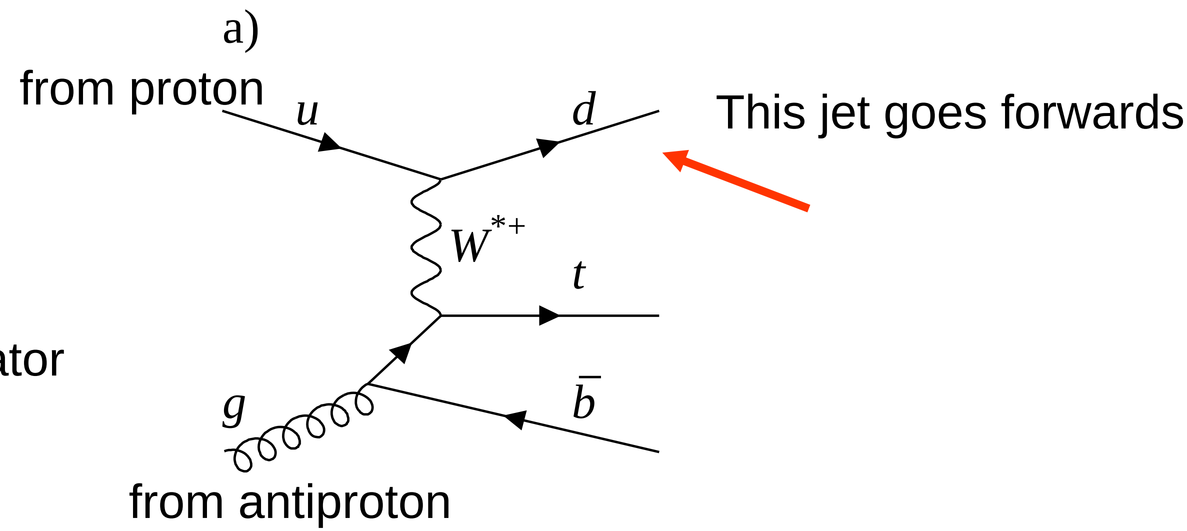
- W+jets backgrounds do not have top quarks in them, so constraining $M_{l\nu b}$=175 gives larger χ^2 values.
- t-tbar backgrounds have extra/missing jets, leptons, and neutrinos. Only rarely is the $M_{l\nu b}$ correctly reconstructed for those.

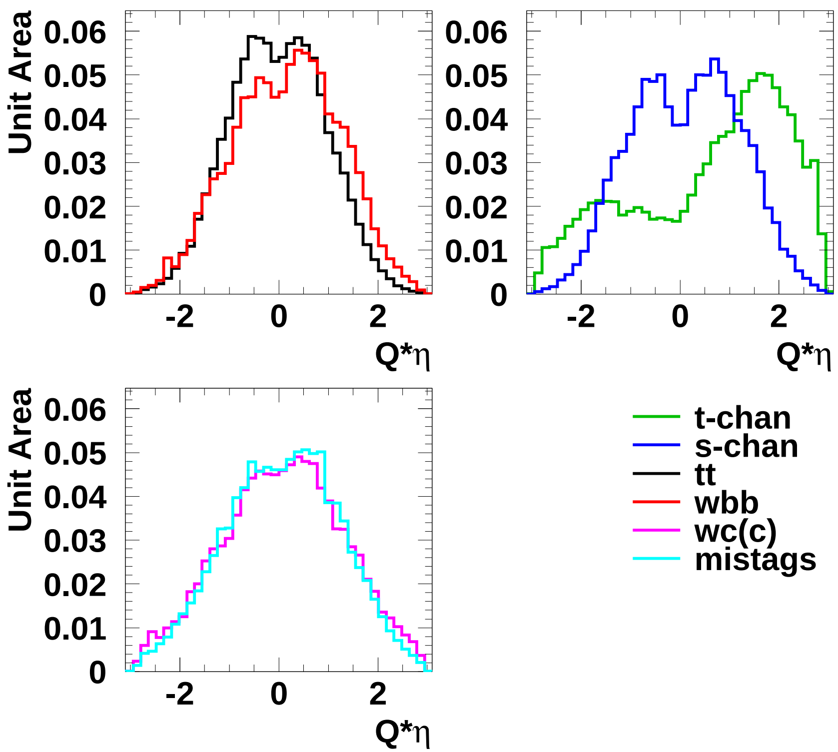


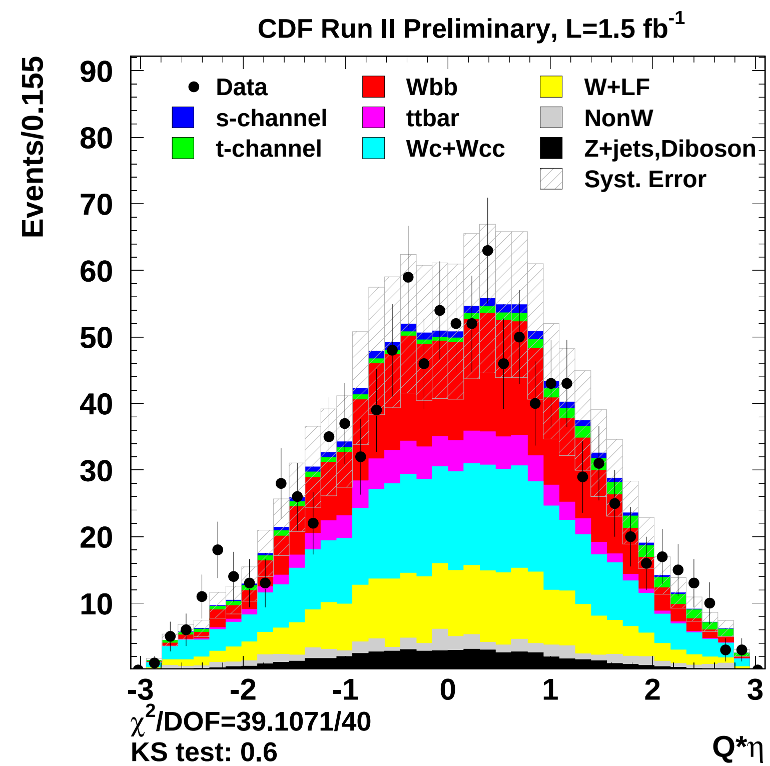


Q×η

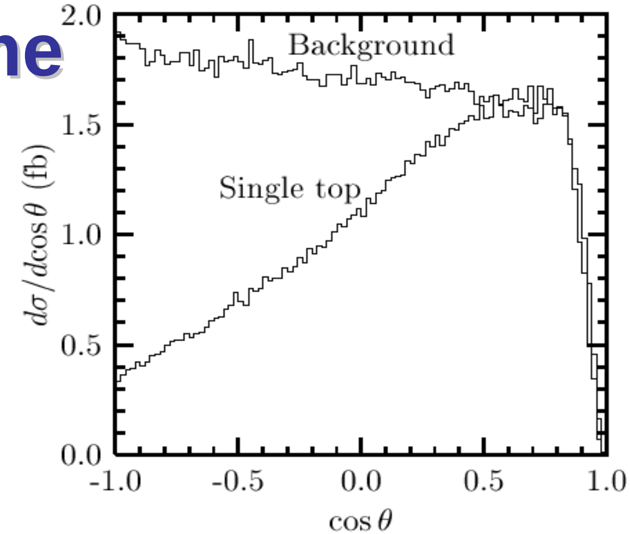
Excellent t-channel signal/background separator Yuan, 1990.





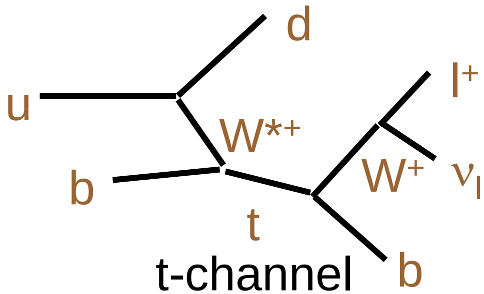


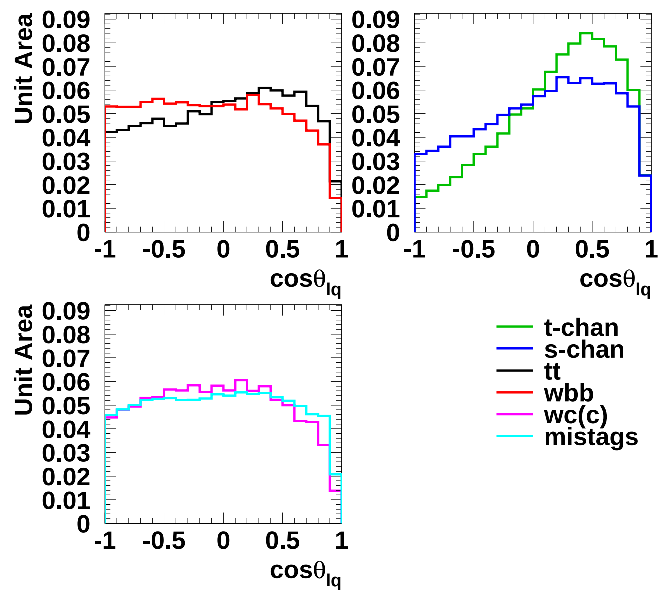
$\cos\theta_{l,\text{other jet}}$ in Top Decay Frame

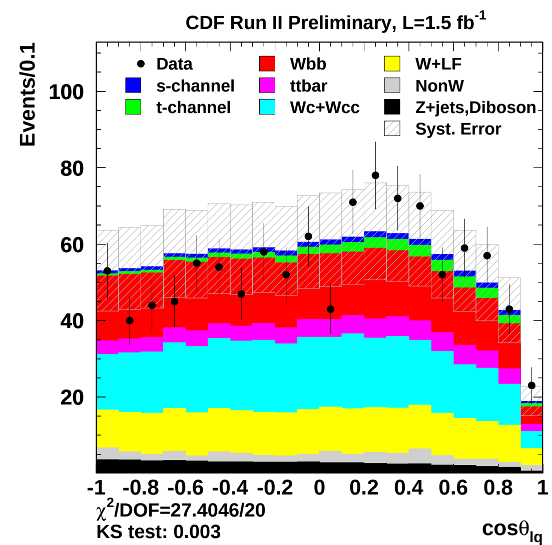


- Relies on top polarization (we are trying to observe single top, assuming SM properties. To measure polarization, we'd have to have a more inclusive selection)
- Shape affected by lepton isolation requirement -- high s/b region next to a cut!

Stelzer, Sullivan, Willenbrock
Phys.Rev.D58:094021,1998.

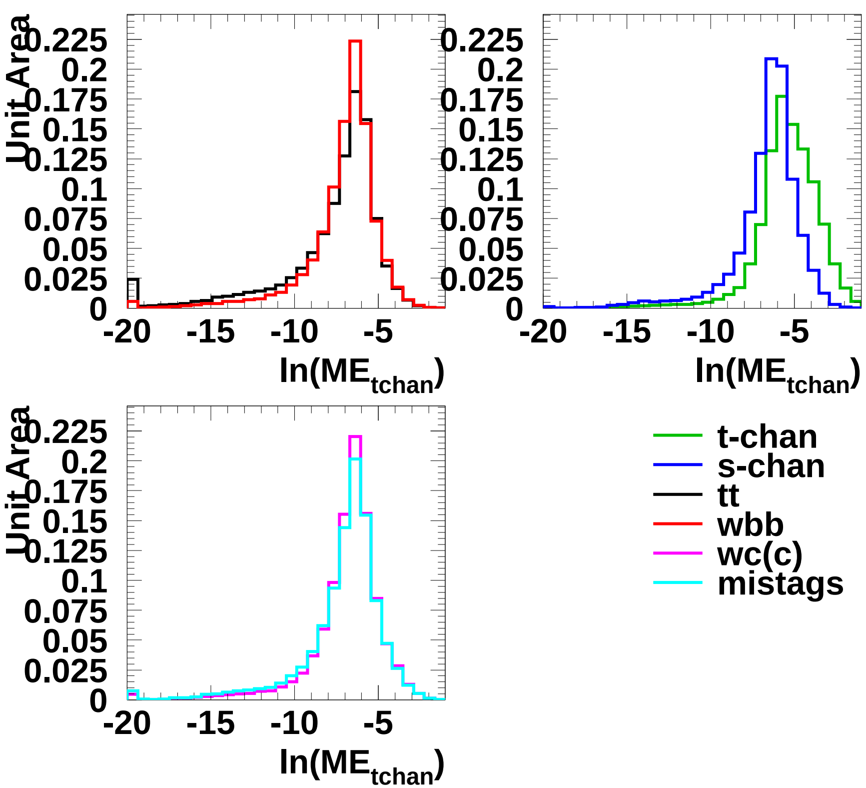


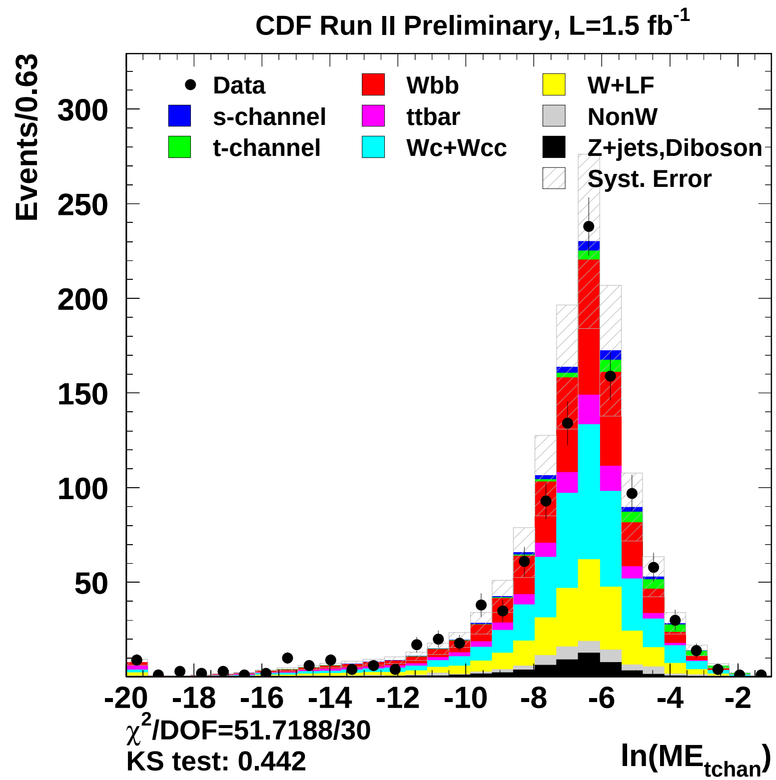




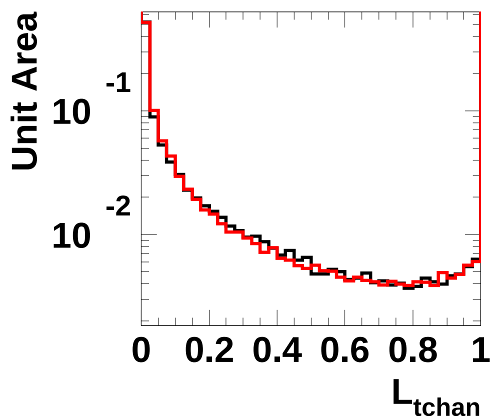
The Matrix Element

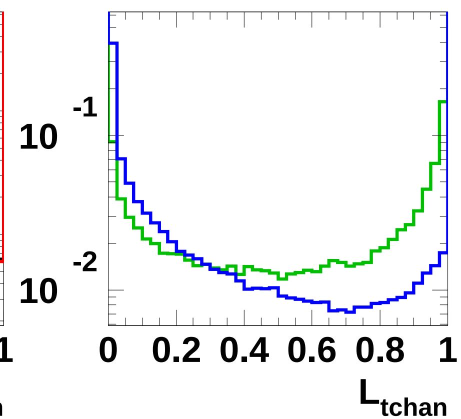
- Mass information factored out – only angle and angle/momentum correlations left.
- Correlated with $Q \times \eta$ and $\cos\theta_{l,jet}$.
- One of our strongest variables!

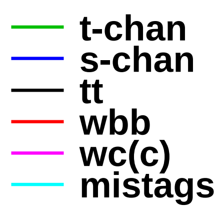




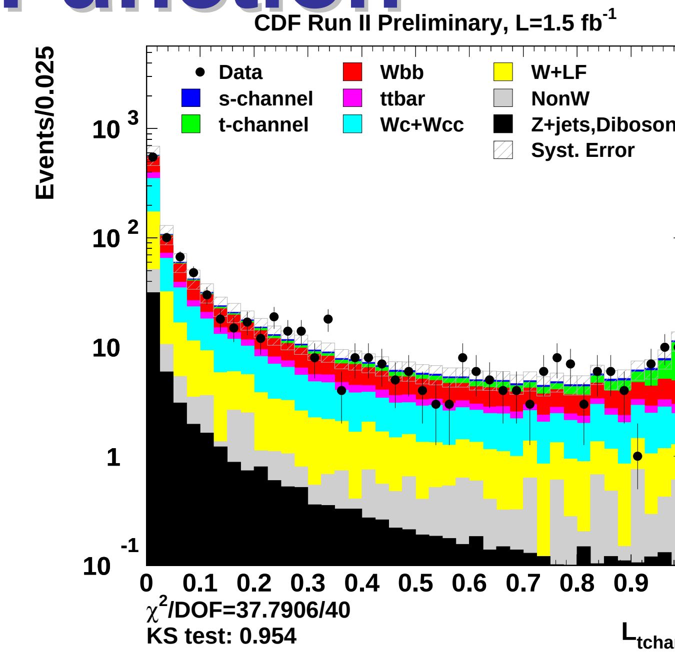
t-Channel Likelihood Function

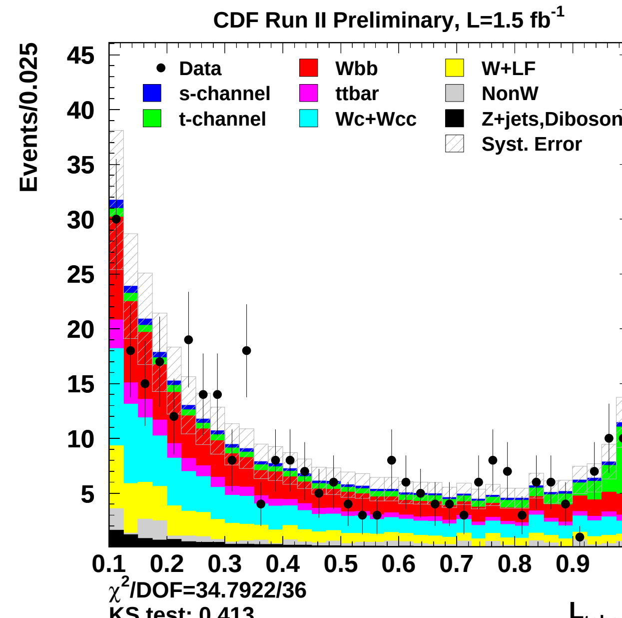






Linear scale, showing $L_{tchan}>0.1$



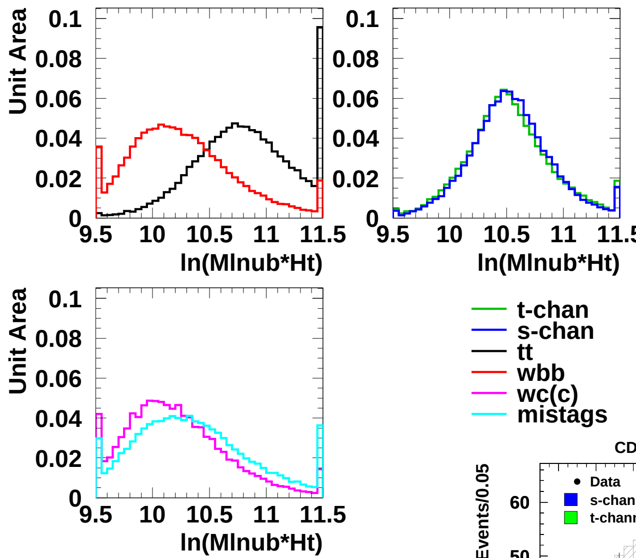


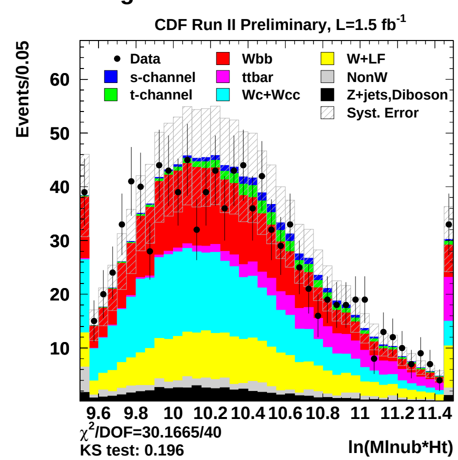
s-Channel Likelihood Function Input Variables

- Same idea as *t*-channel likelihood function, but train it to separate *s*-channel signal from backgrounds.
- Less distinct signal – both jets are b-jets, and $Q \times \eta$ doesn't work. The polarization angle is between the lepton and the beam (heavily sculpted by lepton acceptance).

Variables:

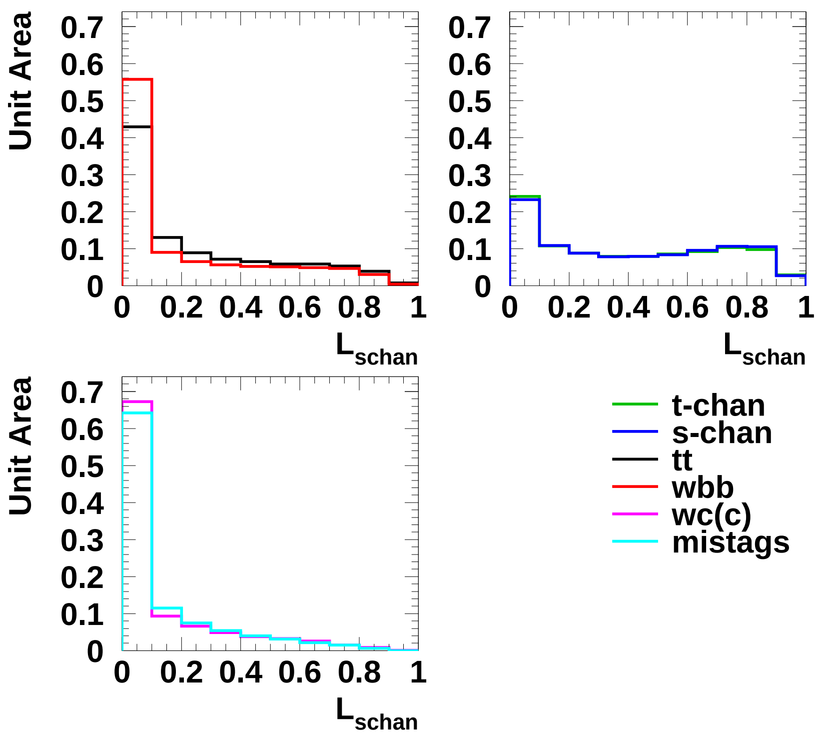
- Jet 1 E_T
- NN b-tag output
- $\log(ME_{s\text{-chan}})$
- $\log(ME_{t\text{-chan}})$ strange, but it works..
- H_T
- $M_{l\nu jj}$
- χ^2 (*s*-channel kinematic solution)
- $\log(H_T \times M_{l\nu b})$ (Undergraduate Mike Wren came up with that one)

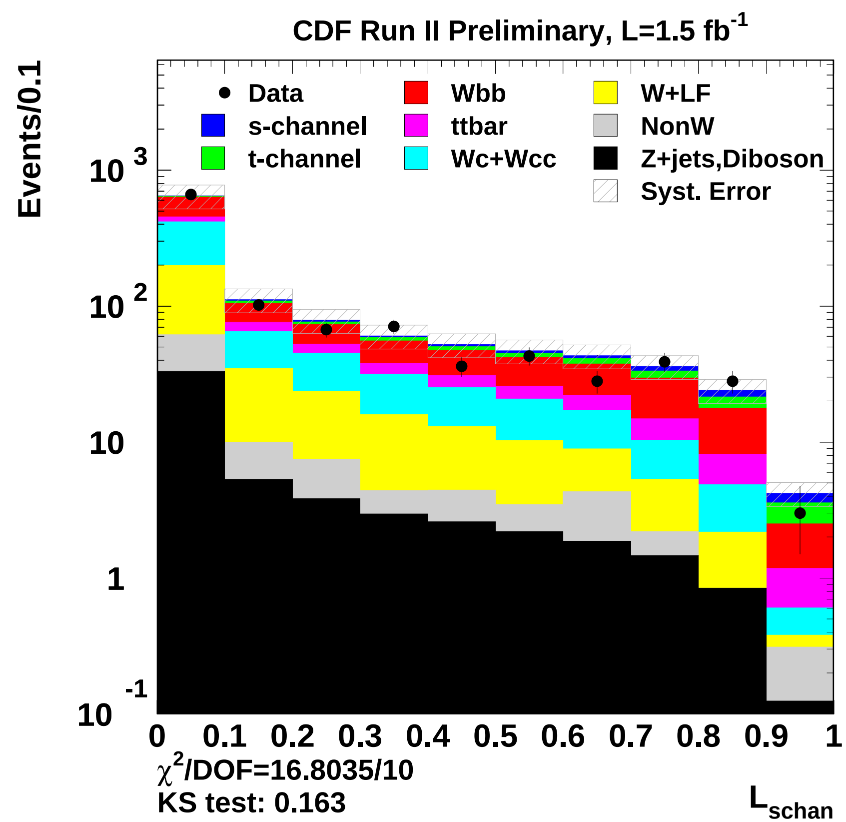




s-Channel Likelihood Function

- Less effective at separating signal from background
- L_s vs. L_t can be used to measure σ_s and σ_t separately





Systematic Uncertainties

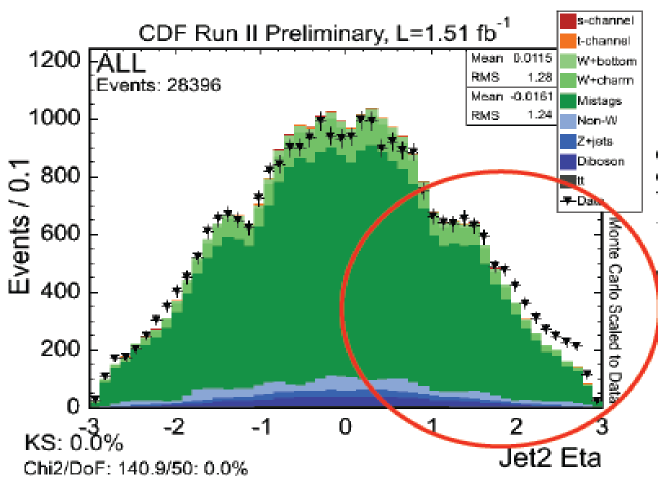
Biggest Uncertainties:

- 35% uncertainty on the rate of W+bbar, W+c(cbar)
- 21% uncertainty on t-tbar cross section
- ISR, FSR, jet-energy scale, PDF uncertainties are all small.
- 6% Luminosity uncertainty (signal and MC-determined backgrounds)
- non-W (QCD) background is 60% uncertain

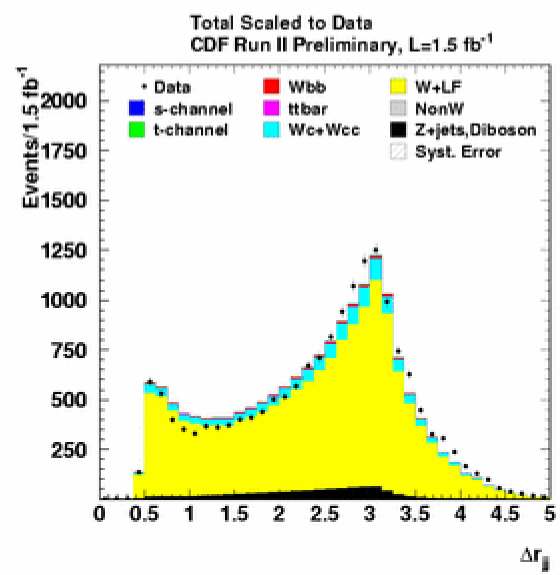
- Shape uncertainties: ISR, FSR, Q^2 scale of MC
  plus mismodeling of input variables
  Jet 2 η
  ΔR_{jj}

1) Beam splash?

2) Jet energy scale in plug?

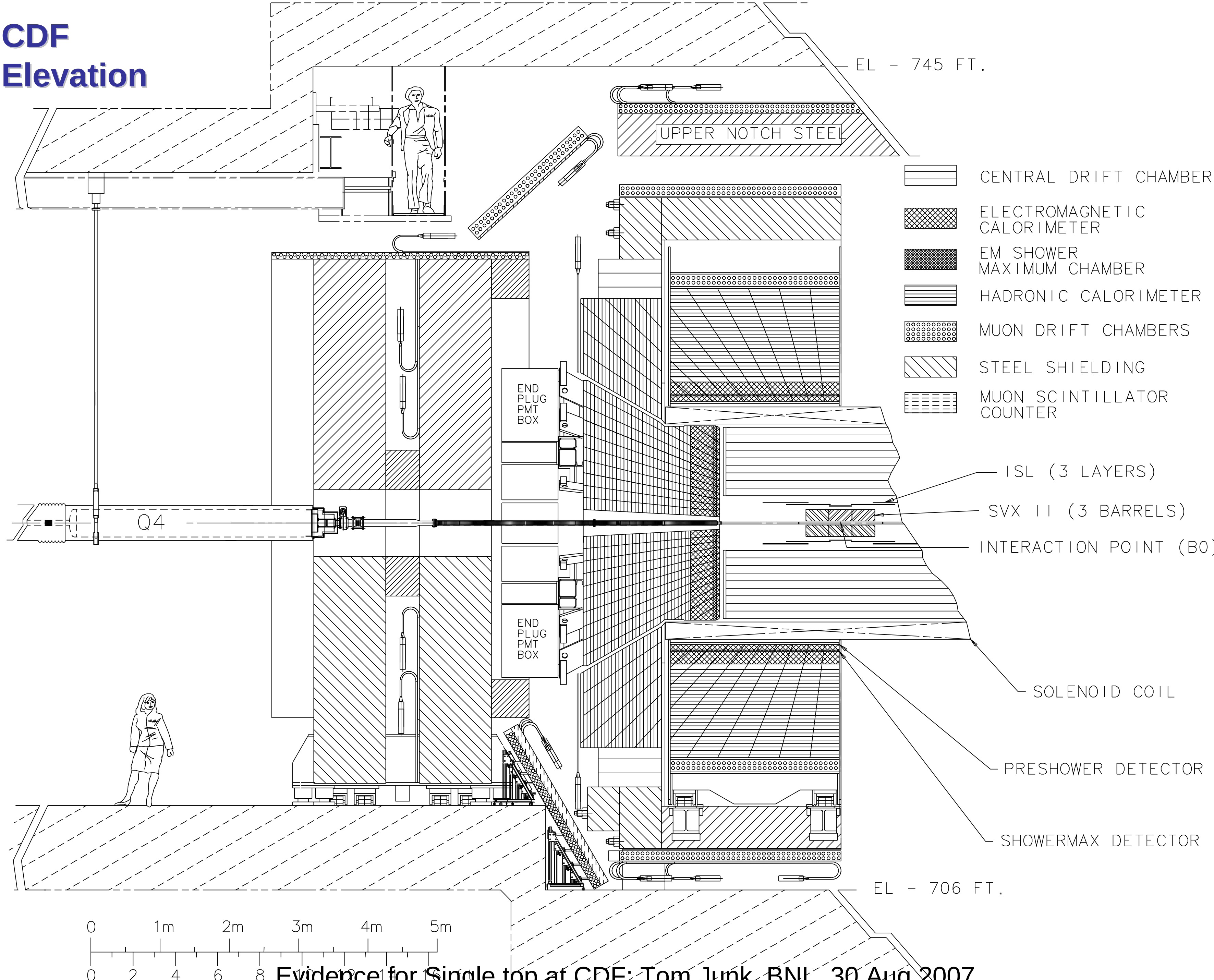


Pre-Tag



Shape errors affect
ability to fit the backgrounds in sidebands and extrapolate to siganl region

CDF Elevation



Hypothesis Testing – p-values

$$-2\ln Q = -2\ln \frac{p(\mathrm{data}|H_1,\hat{\theta})}{p(\mathrm{data}|H_0,\hat{\hat{\theta}})},$$

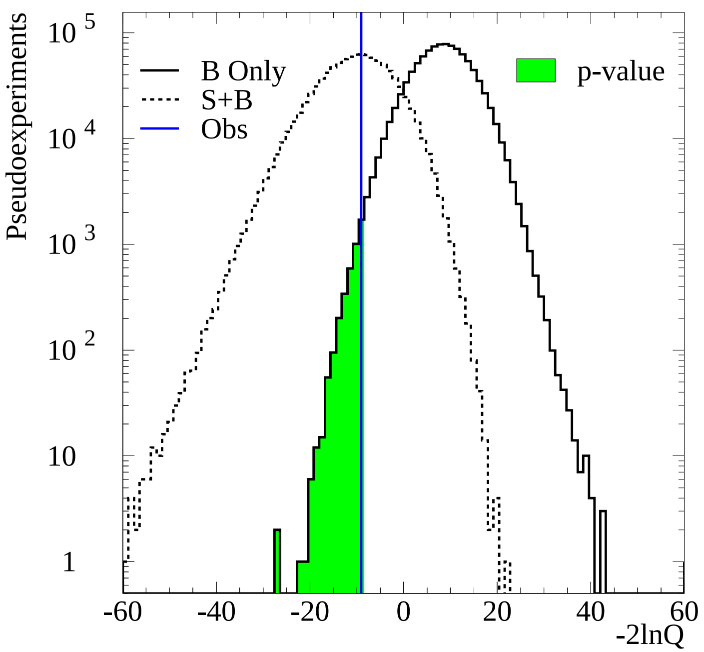
H1 = test hypothesis (signal+background)
H0 = null hypothesis (background only)

θ= nuisance parameters
Hats: two fits, one for H1, one for H0

Observed -2lnQ=-9.03 (favors a signal)

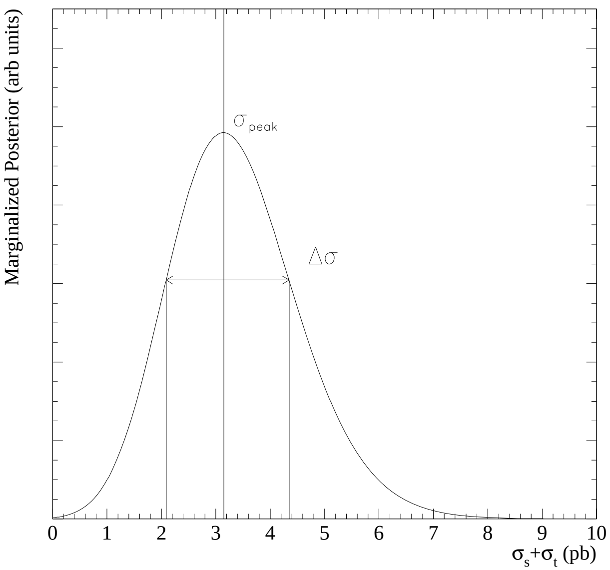
p-value = P(-2lnQ<obs|H0) = 0.0031
Corresponds to 2.7σ

Median expected p-value = 0.0020
Corresponds to 2.9σ



Extracting Information from the Bayesian Posterior

t-channel likelihood output only used

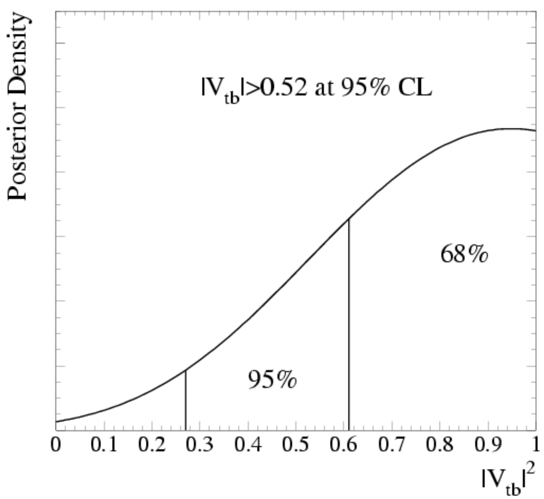


$$\sigma_s + \sigma_t = 2.72^{+1.29}_{-1.12}$$

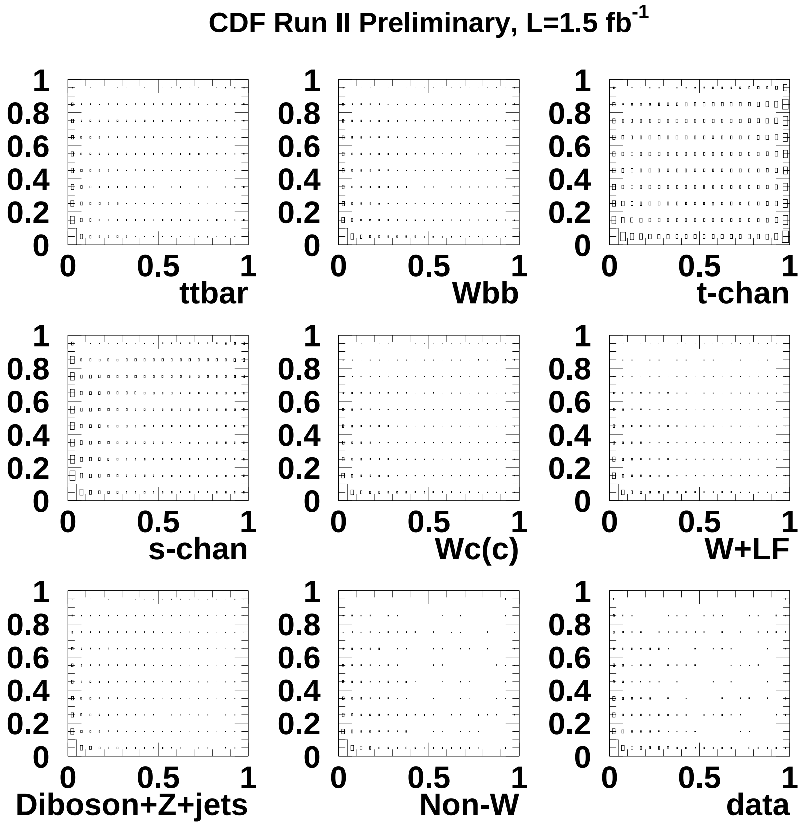
$$\left|V_{tb}\right| = 0.97^{+0.21}_{-0.19} \pm 0.07_{theory}$$

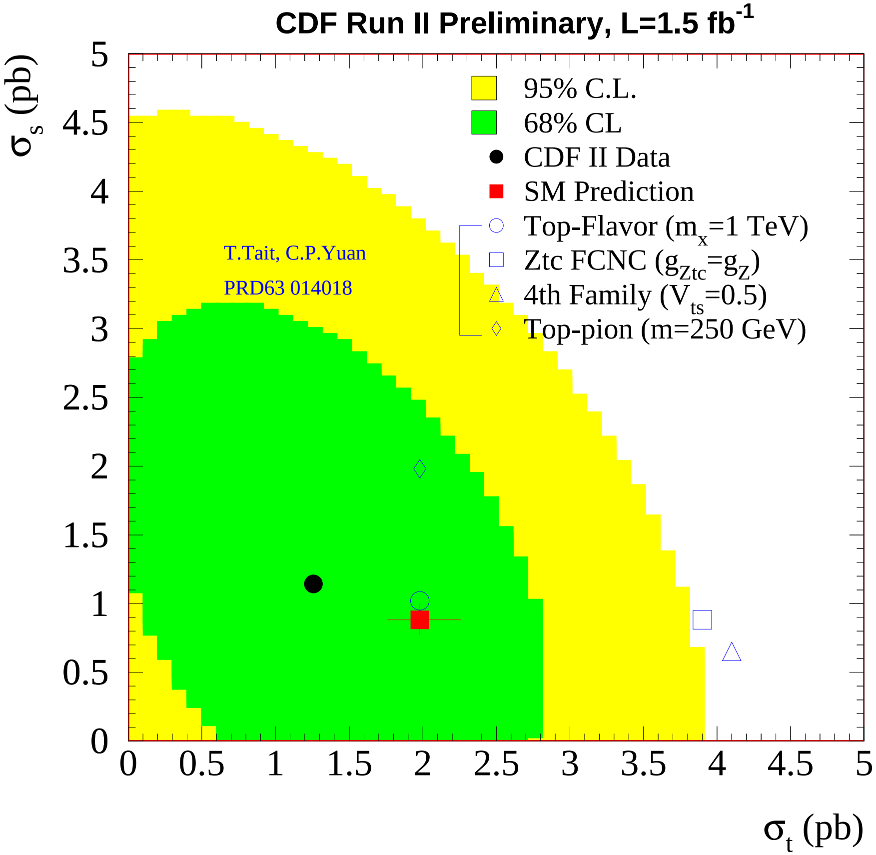
assuming $\sigma_s + \sigma_t$ is proportional to $|V_{tb}|^2$,

Upper limit: 5.14 pb at 95% CL (Bayesian calculation).
Median expected limit in background-only pseudoexperiments: 2.06 pb



The Two-Dimensional Fit for σ_s and σ_t Separately

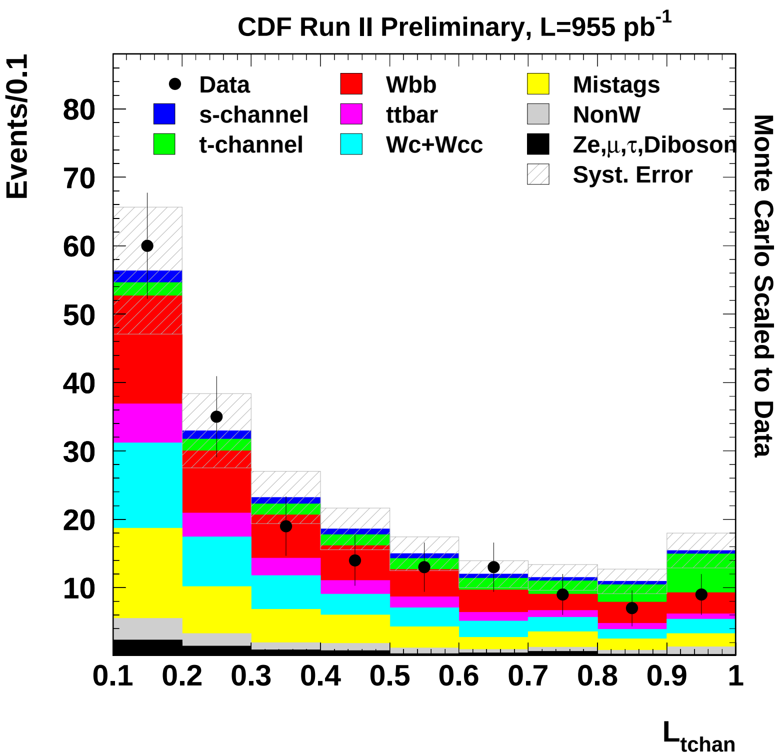


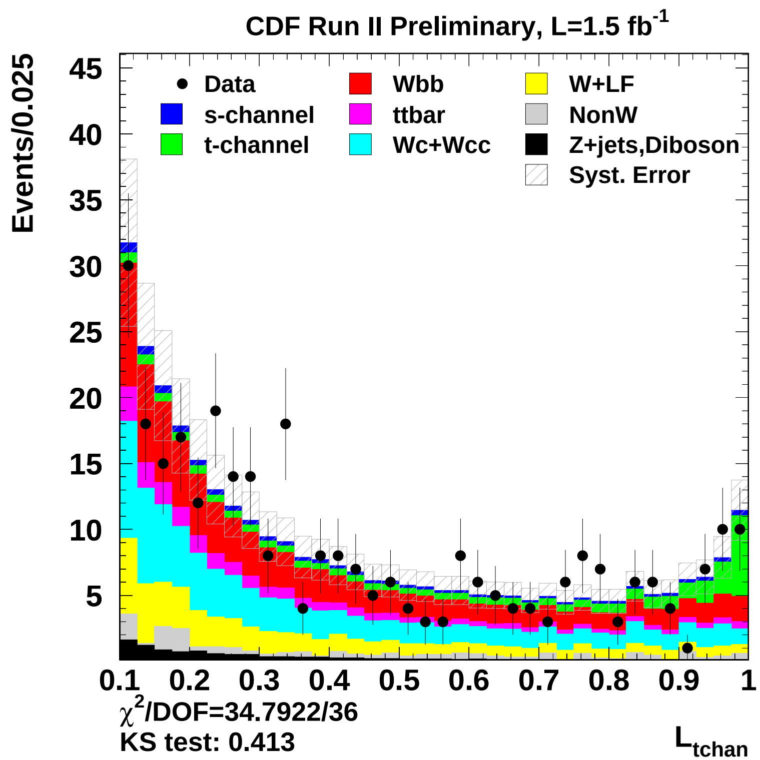


$$\sigma_s = 1.1^{+1.4}_{-1.1}\ \text{pb}$$

$$\sigma_t = 1.3^{+1.2}_{-1.0}\ \text{pb}$$

Differences with the Summer 2006 Likelihood Function Analysis



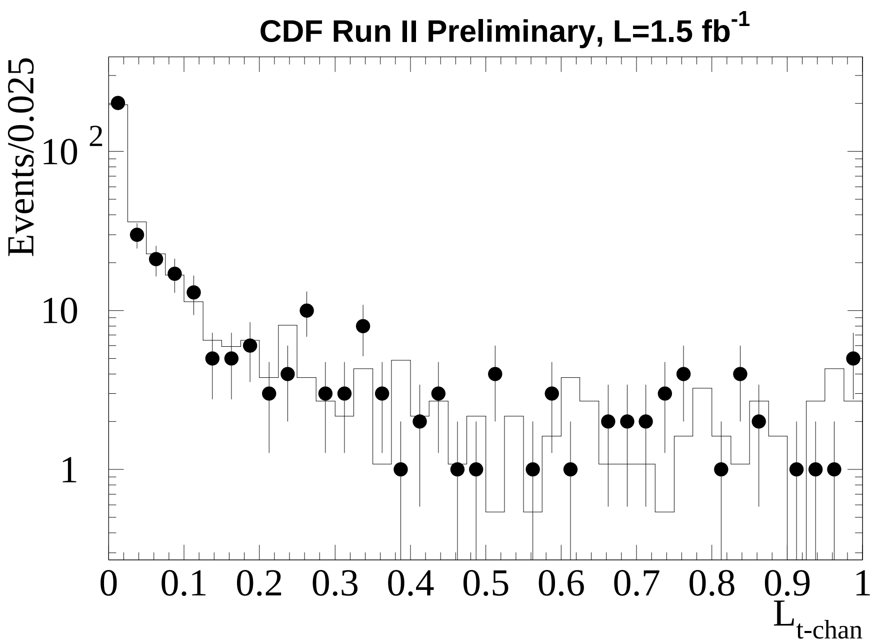


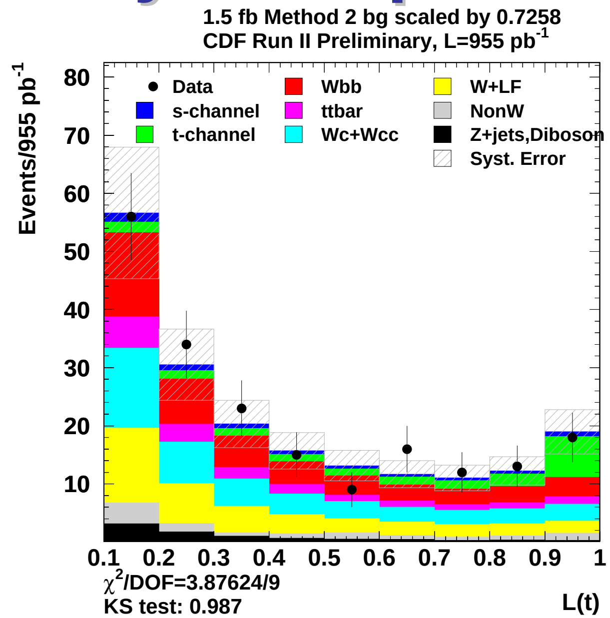
No evidence for Single Top quarks seen.
Limit is $\sigma_s+\sigma_t<2.7$ pb @95%CL

Now we have 2.7σ of an excess
Measured value $\sigma_s+\sigma_t = 2.7$ pb

What Happened? Is it all the new 0.5 fb^{-1} of data?

Is it the New Data or The Analysis Improvements?



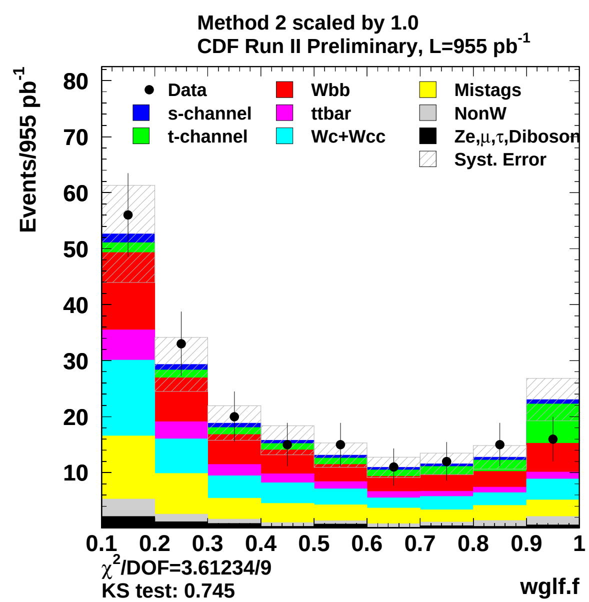


New LF
New cuts
1 fb^{-1} data

Points – last 0.5 fb^{-1} of data
Histogram: First 1 fb^{-1} of data, scaled to match normalization of points.

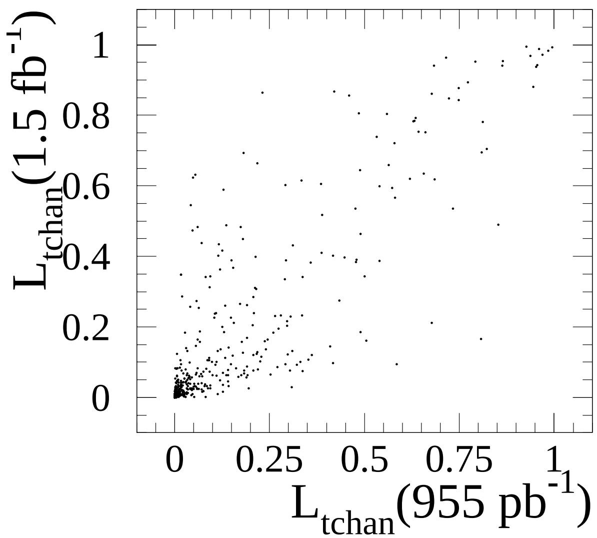
New data are not significantly more lucky than the old data.

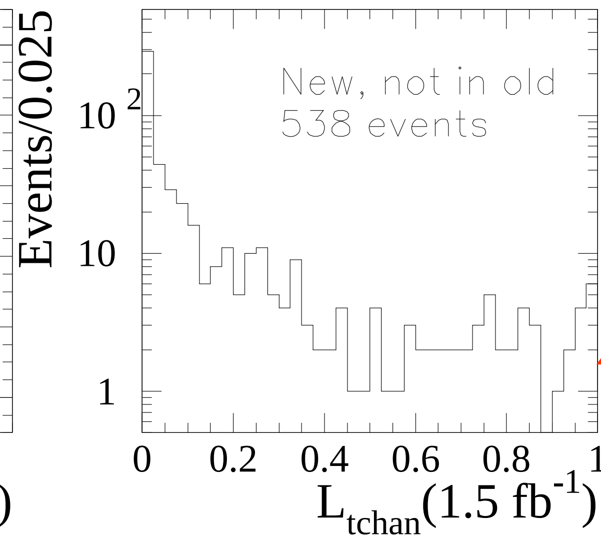
New LF and cuts applied.



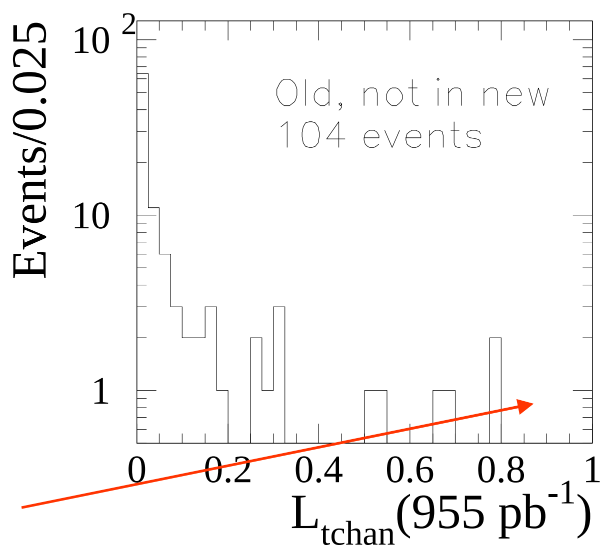
New LF
Old cuts
old bg norm
1 fb^{-1} of data

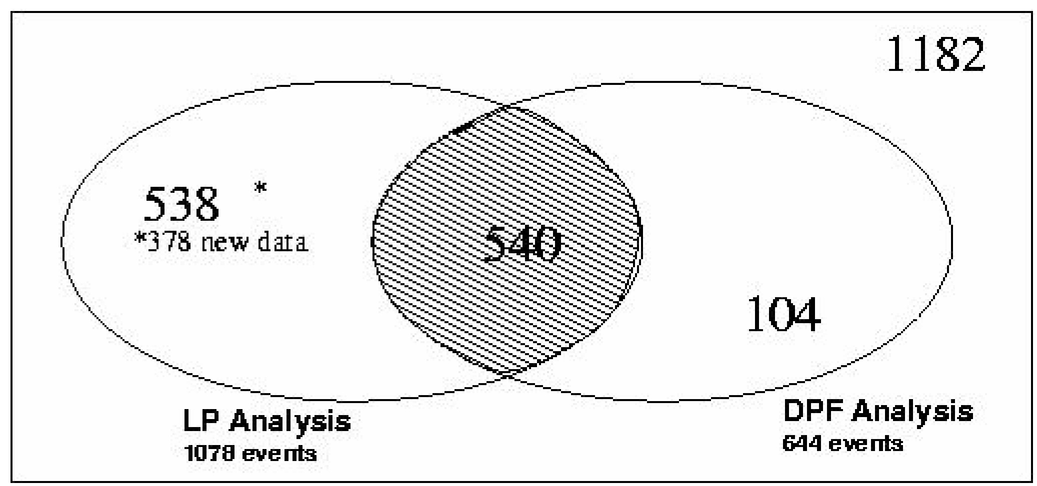
Event Migration





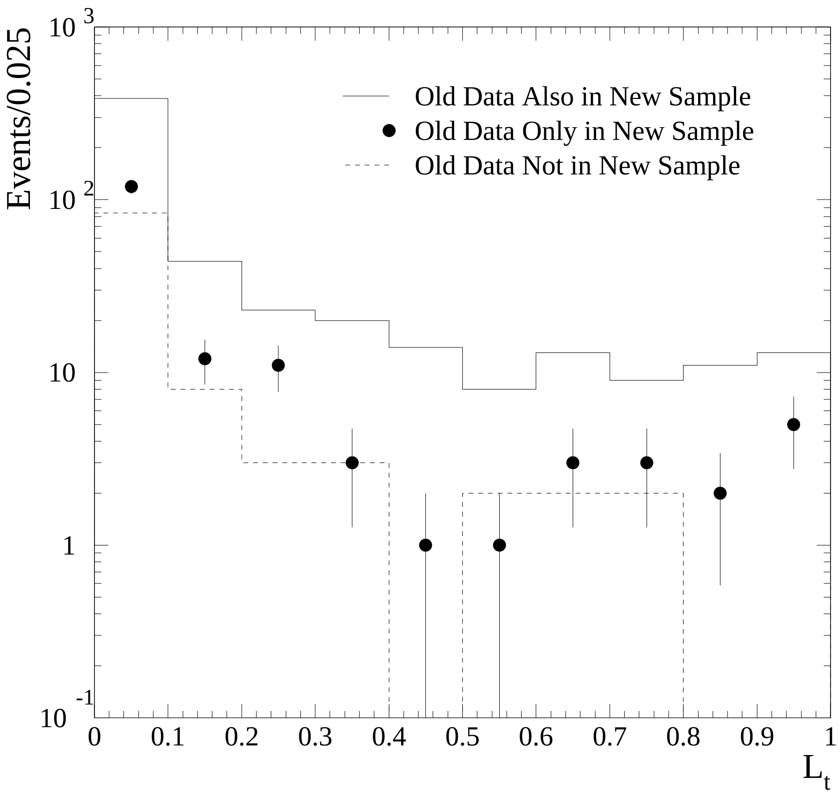
Picked up many new events at high LF





Didn't lose any high-LF events

A look at Just the 955 pb^{-1} Sample – Where are the New Events?



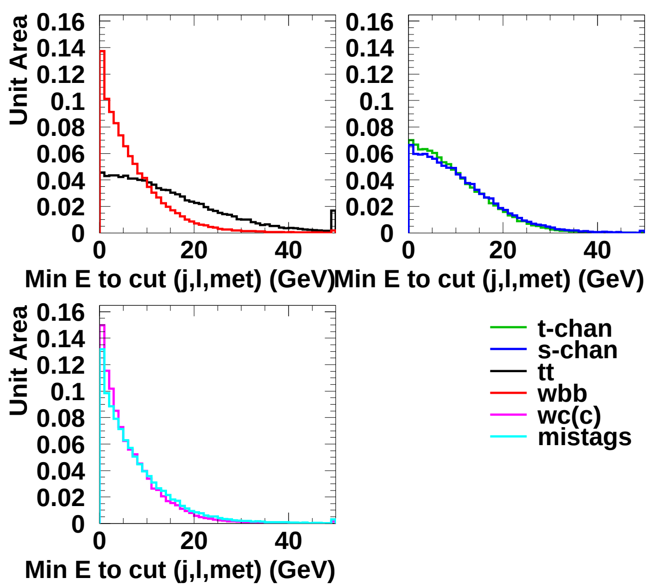
Five new events in last bin, none lost. Events investigated – all are near preselection cuts.

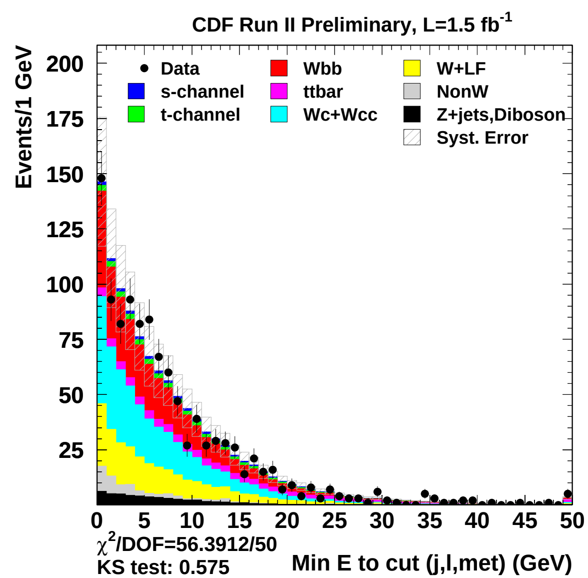
What happened?

1) Recalibration and reprocessing
2) Change in jet energy cuts from 15 GeV after detector calibration, to 20 GeV after detector->hadron-level jet corrections.
3) Changes in cuts Top-group wide, determined long before single-top processing. Need to keep selection the same so that we can combine the result with the rest of the group.

High-Significance Events Near Cuts

- Isolation – removes QCD background, but signal likes to have the lepton close to a jet
- Jet energies and Missing Et have falling spectra, even for signal. Cuts are designed to keep within the validity region of the jet corrections (probably should cut even lower on jet energies, but need a manpower push to calibrate them)
- t-channel signal throws one jet at very high eta, challening our ability to detect it. Geometrical detector acceptance and modeling of beam-splash and energy calibration set that cut.
- Lepton energy cut designed to get away from the 18-GeV trigger threshold





Matrix-Element Search For Single-Top Production

- Main difference with the likelihood analysis is the handling of reconstruction ambiguities

Start with Fermi's Golden Rule: Cross sections are proportional to matrix elements squared and phase space

$$d\sigma = \frac{1}{2E_1 E_2 |v_1 - v_2|} \prod_i \left(\frac{d^3 p_i}{(2\pi)^3 2E_i} \right) |M|^2 (2\pi)^4 \delta^{(4)} \left(p_1 + p_2 - \sum_i p_i \right)$$

If we had perfect measurements of the final-state particles, and had matrix elements for all contributing processes, we'd be able to say what the "purity" of each event is – chance that it came from each contributing process.

But: We miss some particles entirely
We mismeasure and misidentify particles
We don't trust LO matrix elements to predict QCD processes well enough.
Other information, such as NN b-tagger score

Matrix-Element Mechanics

- Calculate probability density of an event resulting from a given process

Phase space factor: Integrate over unknown or poorly measured quantities

Parton distribution functions

$$P(p_\ell^\mu, p_{j_1}^\mu, p_{j_2}^\mu) = \int d p_{j_1}^\mu dp_{j_2}^\mu dp_\nu^z \sum_{comb} \phi_4 \, | M(p_i^\mu) |^2 \frac{f(q_1) f(q_2)}{|q_1||q_2|} W_{jet}(E_{jet}, E_{part})$$

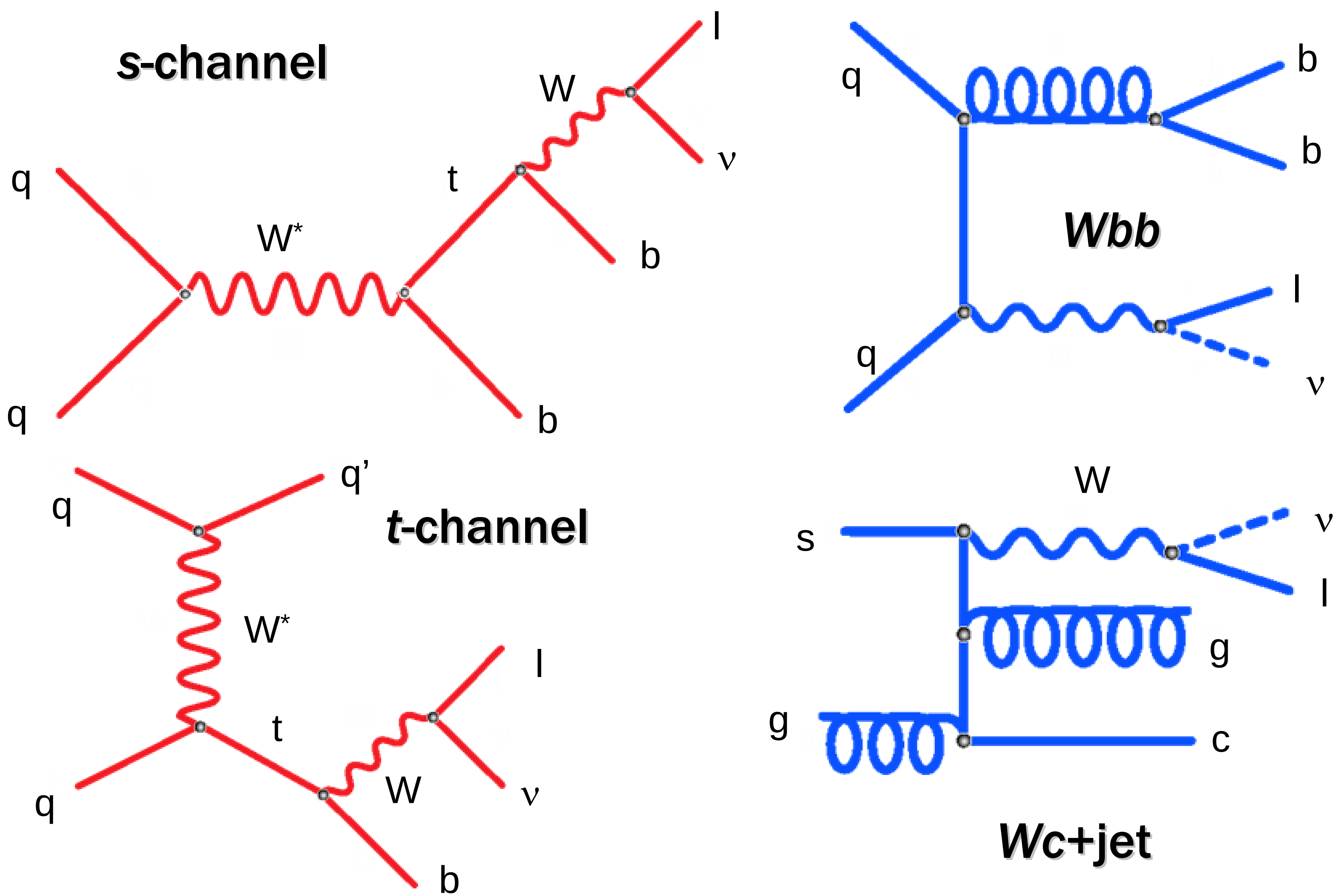
Inputs: lepton and jet 4-vectors – no other information needed!

Matrix element: Different for each process. Leading order, obtained from MadGraph

Transfer functions: Account for detector effects in measurement of jet energy

- Uses full kinematic information of an event to discriminate signal events from background events

Matrix elements used



Matrix Element Discriminant Variable

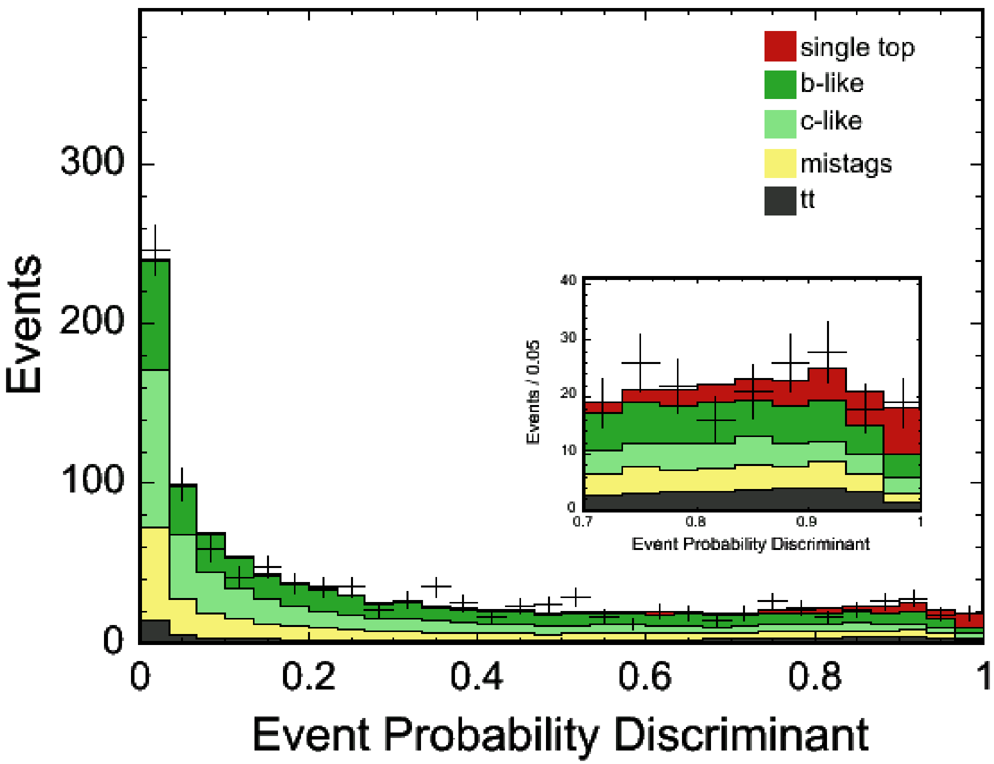
- Have P's for each contributing process (W+LF is a lot like Wcc, Wbb)
- Combine with b-tag NN score to get a single variable to rank events

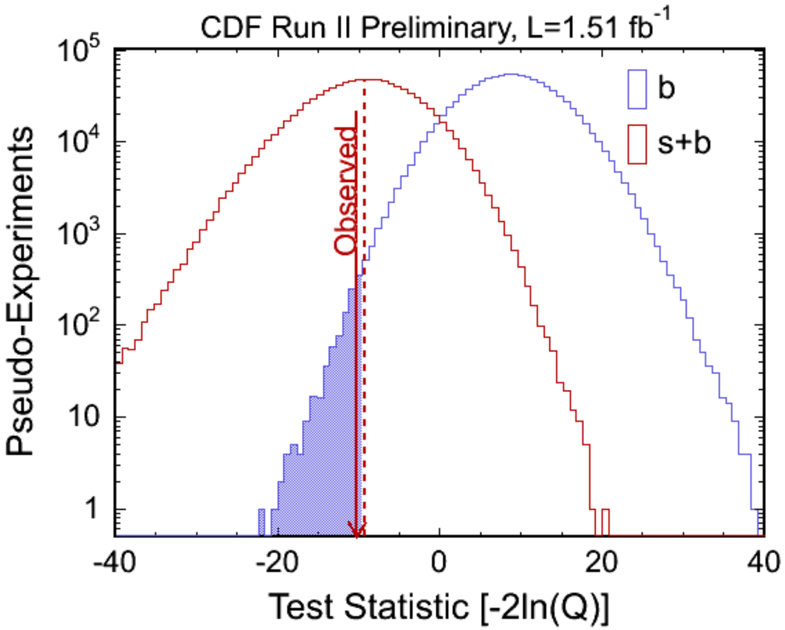
$$EPD_{1-tag} = \frac{b\left(\alpha P_{s-channel} + \beta P_{t-channel}\right)}{b\left(\alpha P_{s-channel} + \beta P_{t-channel} + \gamma P_{Wbb}\right) + (1-b)\left(\delta P_{Wcc} + \varepsilon P_{Wc}\right)}$$

α, β, δ, ε are adjustable parameters to optimize sensitivity
b is b-tag probability from the NN b-tagger

Double-tagged events separated out – same formula, but has
b-tag probabilities appropriate for double tags

Final Discriminant Output and p-value

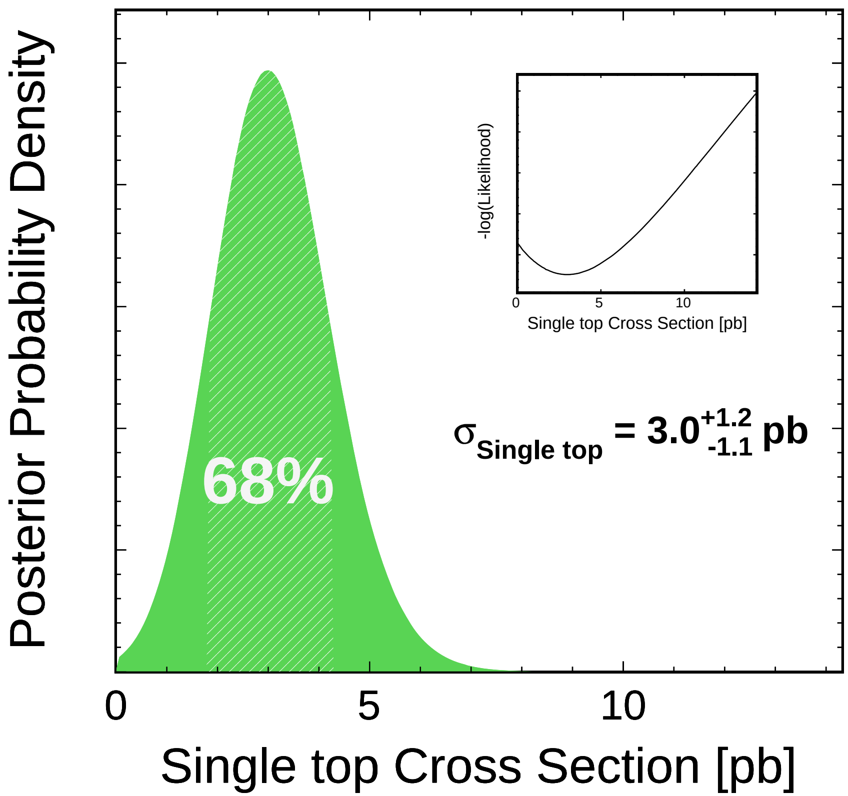


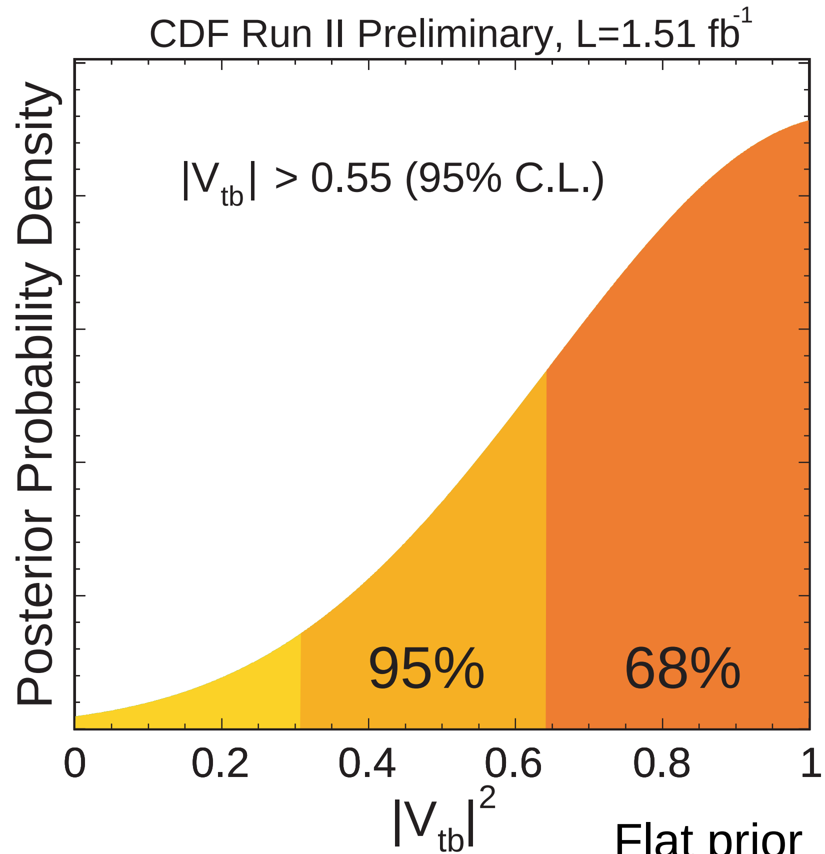


Expected p-value: 3.0σ
Observed p-value: 3.1σ

Evidence for Single Top Production!

Measurement of $\sigma_s+\sigma_t$ and $|V_{tb}|$ with the Matrix Element Analysis



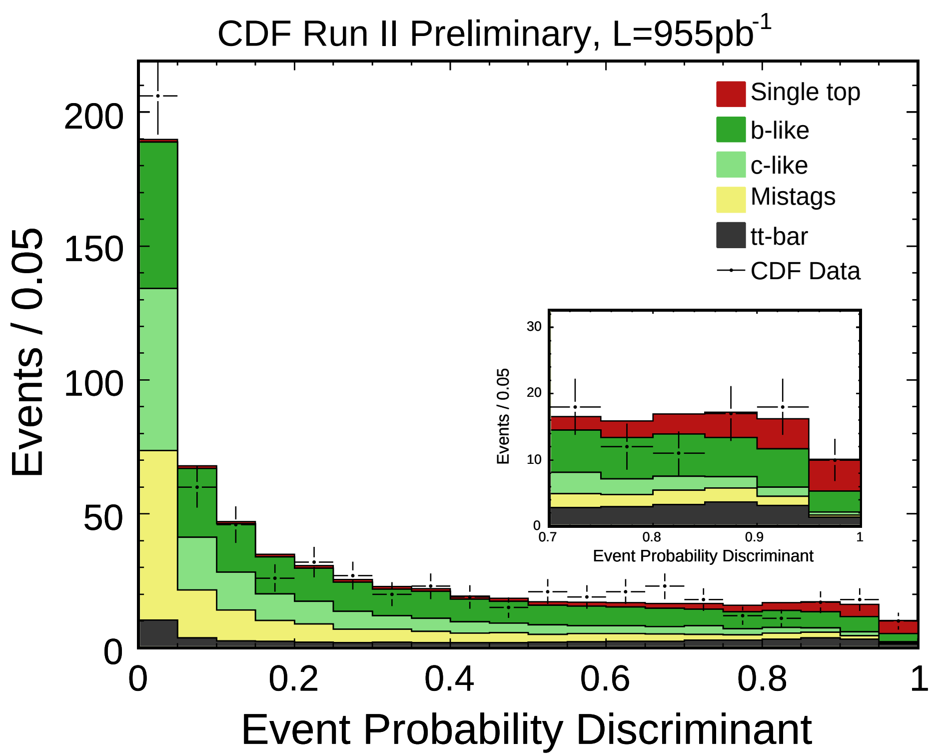


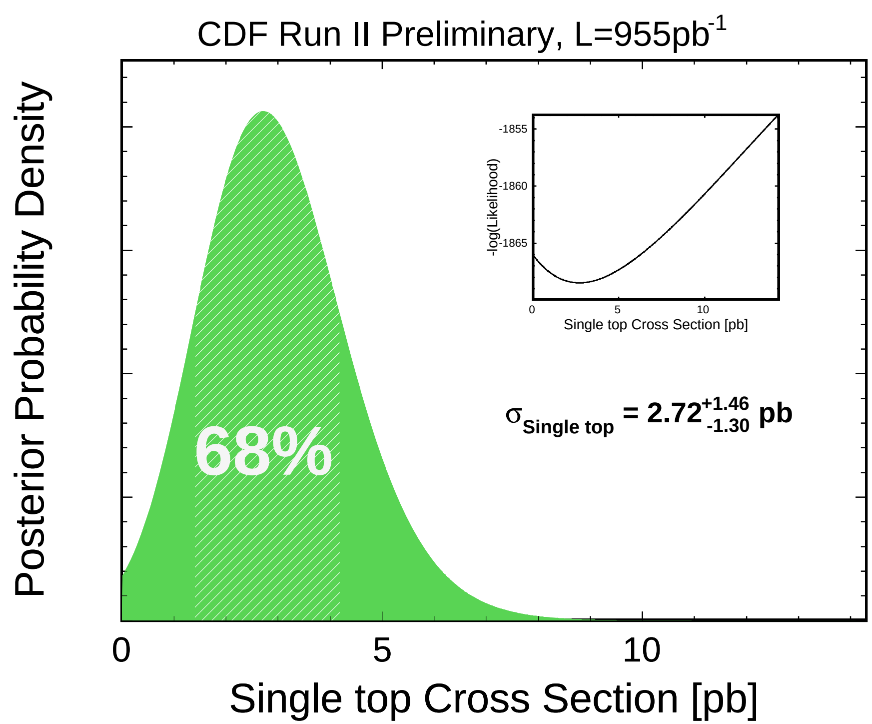
Flat prior in $0<|V_{tb}|^2<1$

$|V_{tb}|= 1.02 \pm 0.18$ (experiment) ± 0.07 (theory)

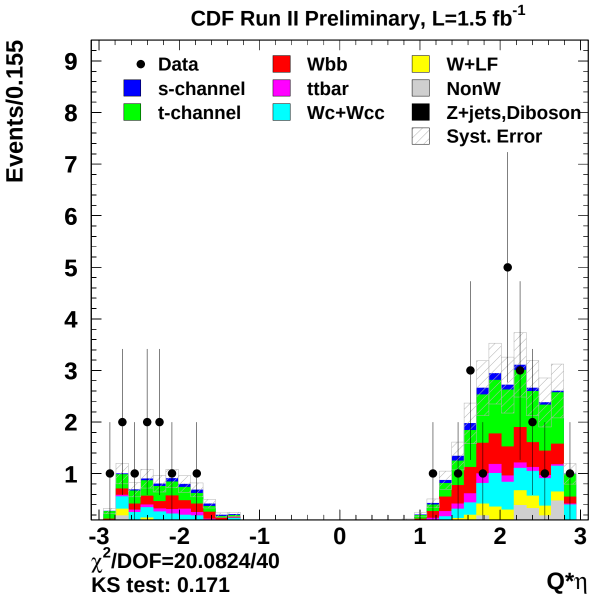
Matrix Element Analysis Results Similar to 1 fb^{-1} Results

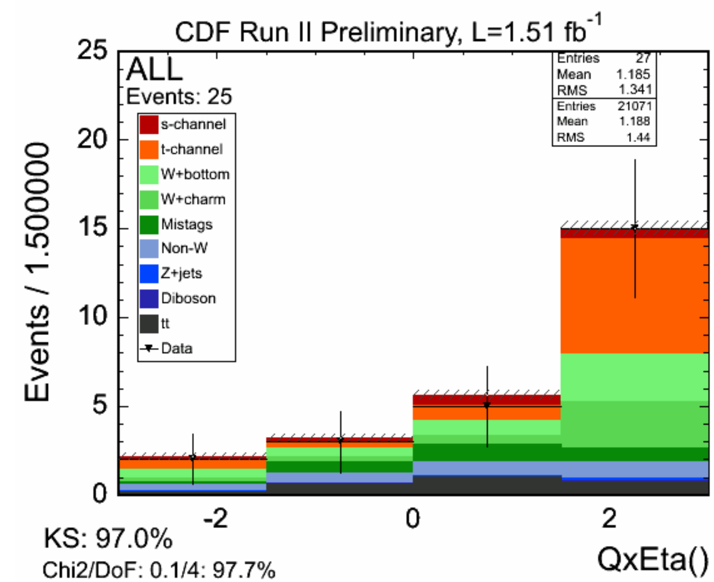
- Sensitivity extrapolates well, but there's a story
  - Analysis improvements (single, double tag, transfer functions)
  - Higher background estimates

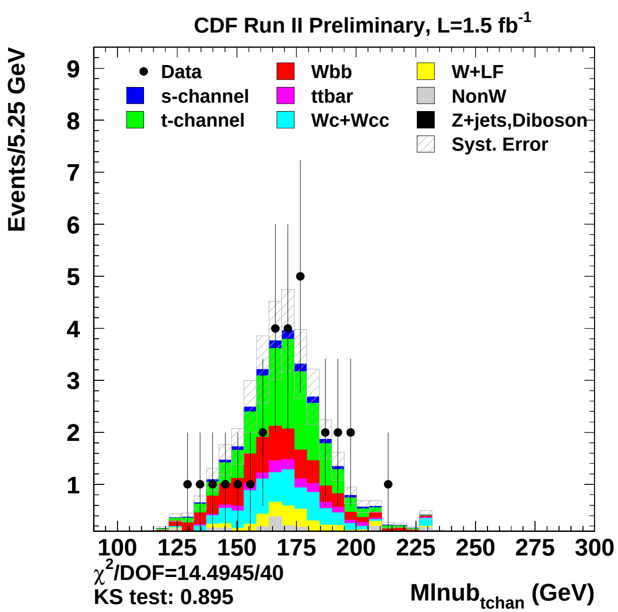


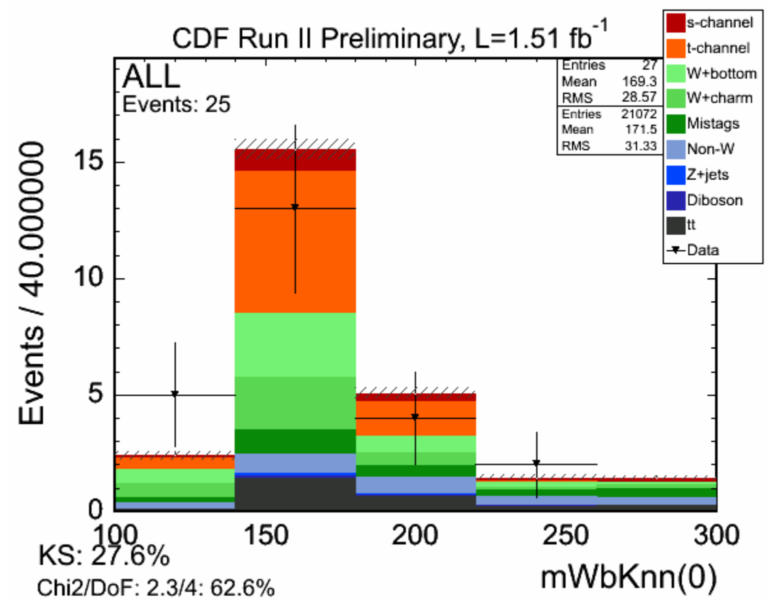


ME and LF High-Score Events do no Completely Overlap









Future Plans for Single Top at CDF

- Big push for Lepton-Photon is over. Preliminary LF, ME analyses done
- NN analysis delayed due to personpower availability but will finish by late 2007
- Update all three analyses with 1.9 fb^{-1} of data by December
- Analysis upgrades:
  - Additional triggers (MET+jets for missing leptons)
  - Split single and double tags in LF analysis

- Combine analyses!
  - Interesting problem – analyses select all the same events! Expect large correlations.
  - 2006 analyses were ~60% correlated with each other.
  - DØ-style combination – BLUE-style cross-section average
  - CDF-internal combination of 2006 results: construct a meta-discriminant out of the separate analyses discriminants. Use NN or just a linear combination. Other methods under study

    Preliminary internal combination of 955 pb^{-1} of data

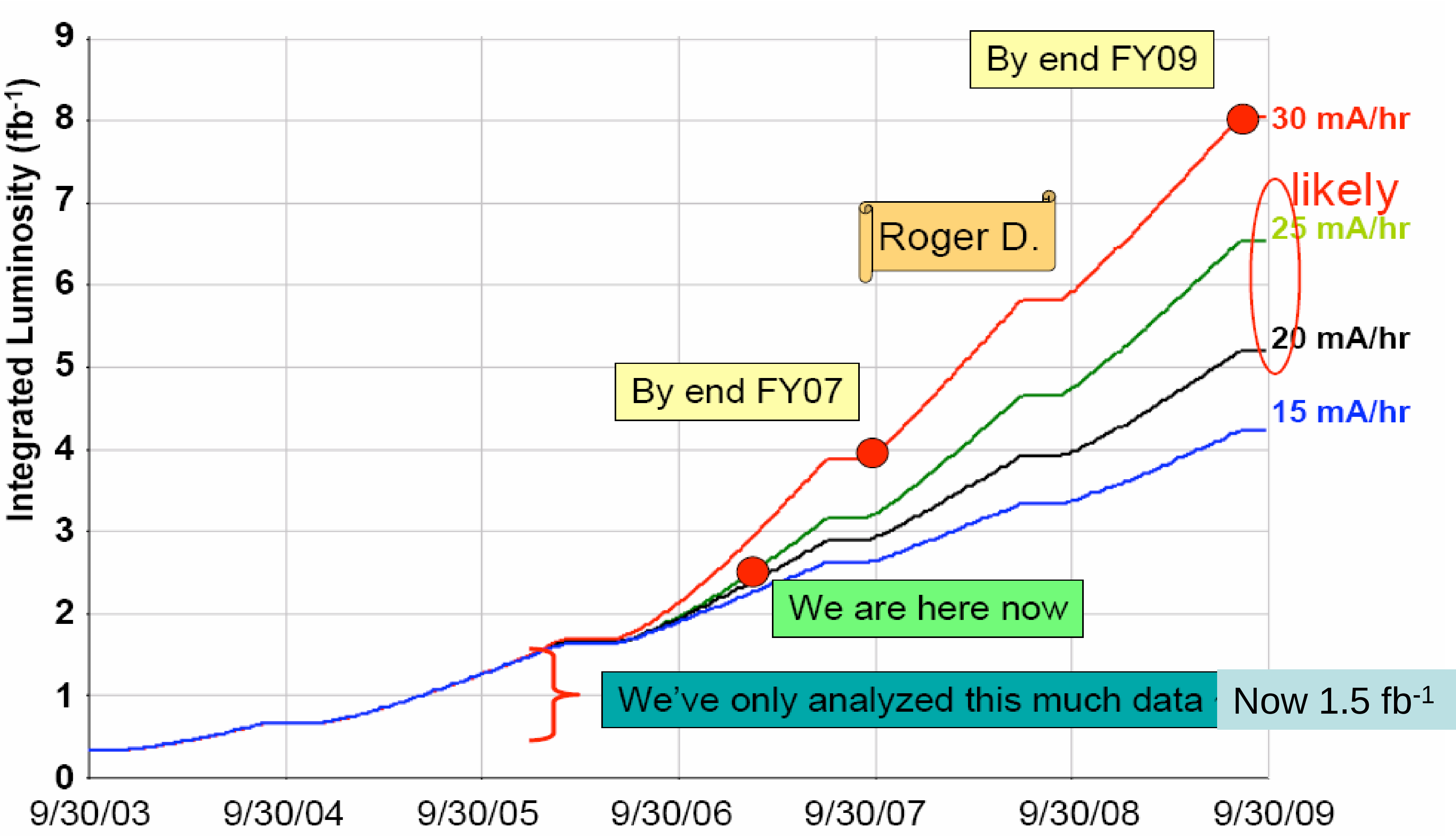
    LF sensitivity: 2.0σ

    ME sensitivity: 2.4σ

    NN sensitivity: 2.6σ

    Combined sensitivity: 3.0σ -- Combining these may get ~4σ

Projecting the Luminosity out to 2009



Roger Dixon, Beams Division

Projections depend on antiproton stack rate.

The Plan – Observe Single Top Quark Prodution!

And start to measure its properties precisely

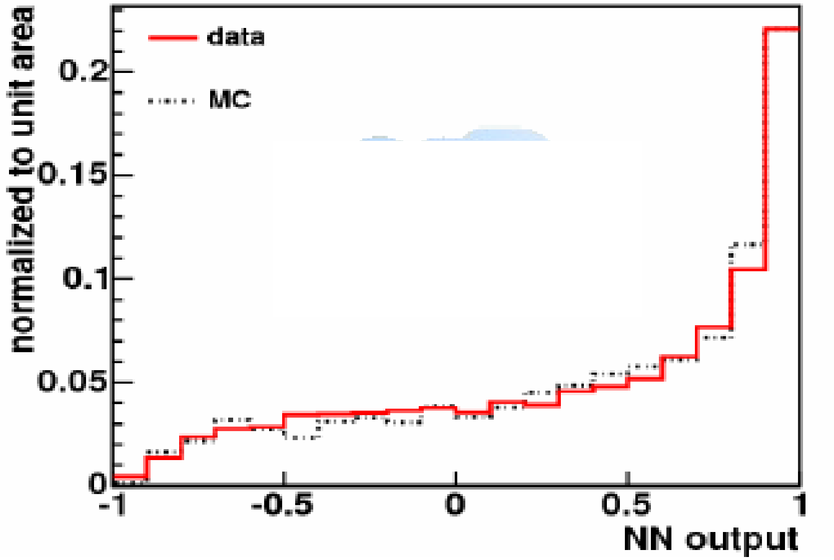
Backup Slides

Heavy Flavor Normalization

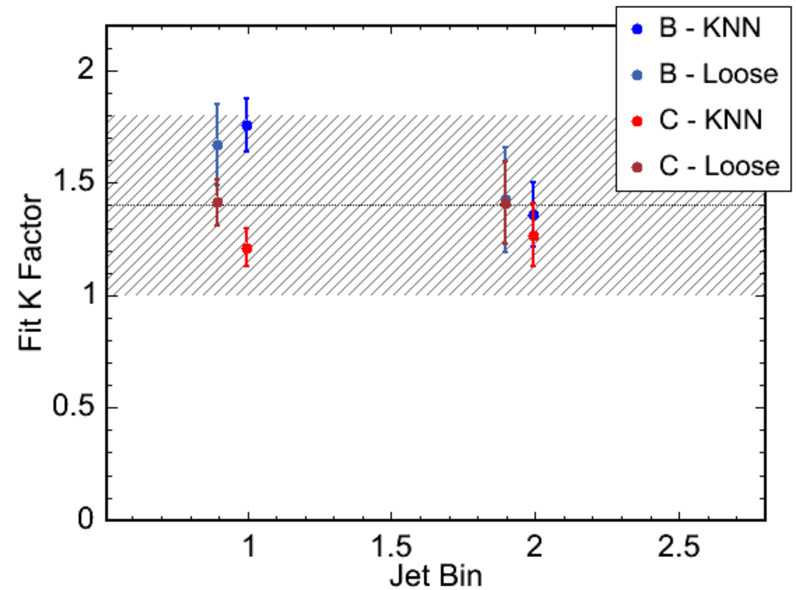
- Improve heavy flavor estimate by calibrating it in W+1 jet side band
- Take advantage of NN based flavor separator
- Compare Loose Secondary Vertex mass and NN flavor separator output:
  - consistent results within errors
- K-factor for heavy flavor:

1.4 ± 0.4

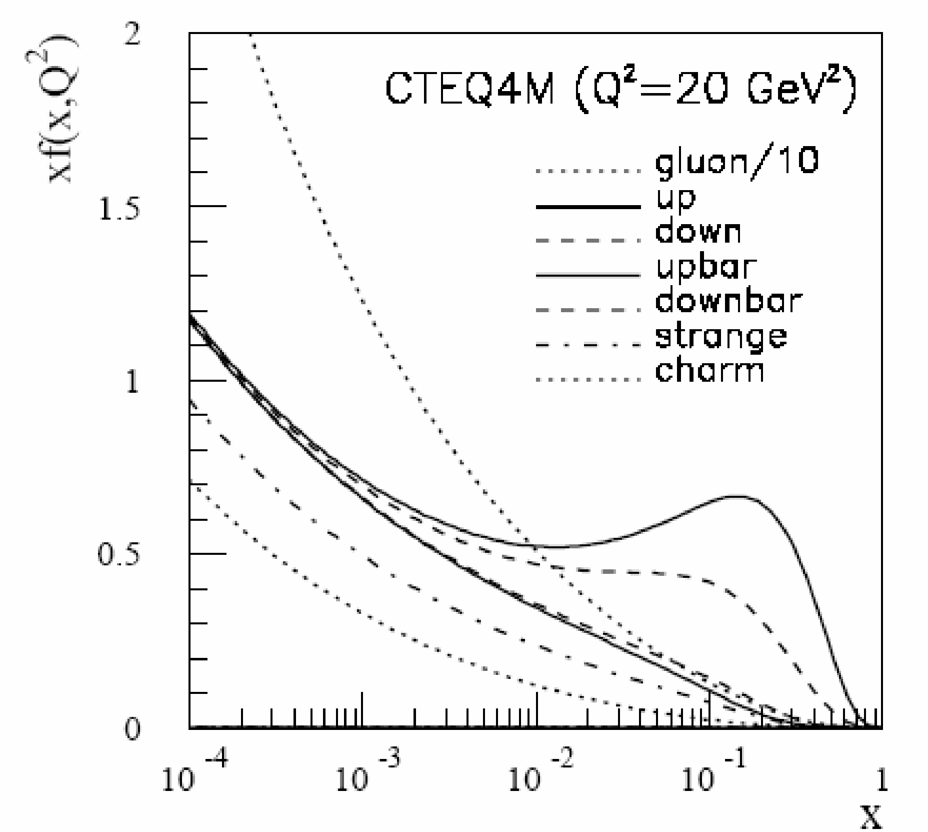
- Applied to predict W + Heavy Flavor content of W + 2 jets bin

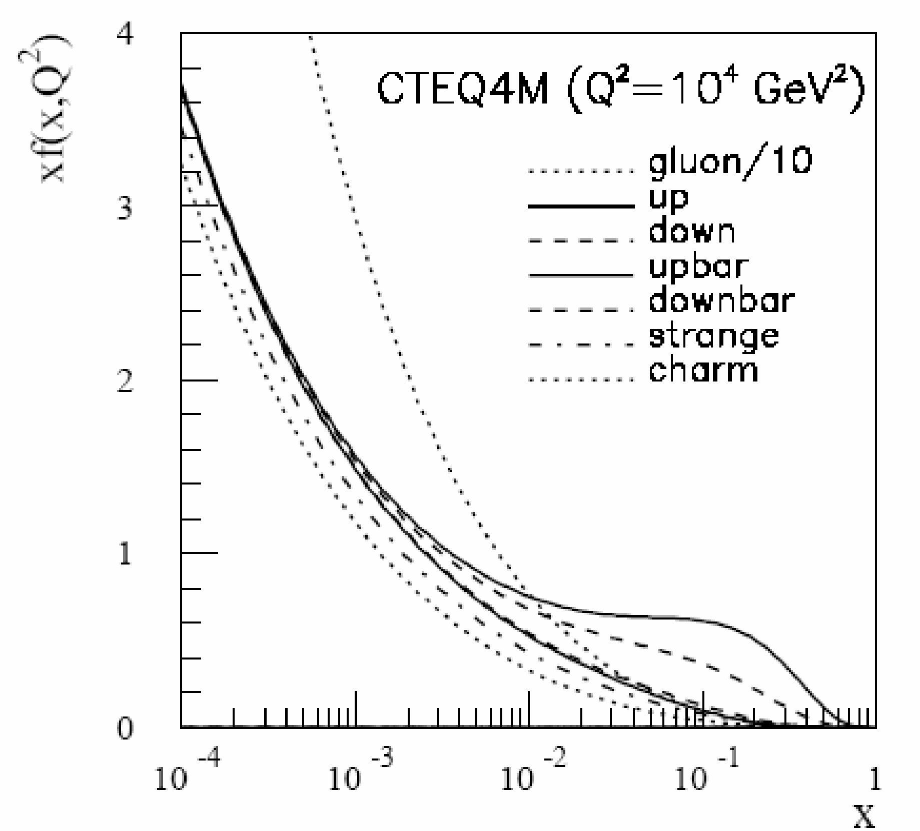


mistags / charm .... beauty



Parton Distribution Functions of the Proton





"The LHC is a gluon-gluon collider" (approximately).

CMSSM Favors m_H <120 GeV

- Bayesian scan over CMSSM parameter space.

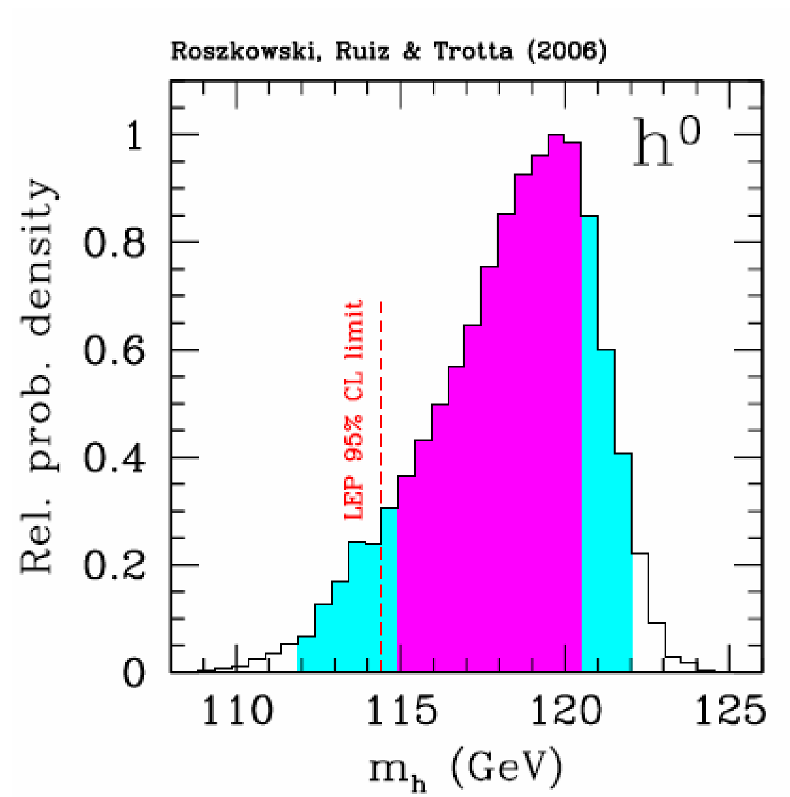
- Inputs
  - Direct LEP2 Higgs searches
  - Precision EW
  - Muon g-2
  - WMAP assuming CDM=neutralinos: $\Omega_\chi h^2$
  - B_s Mixing Rate: ΔM_{B_s}
  - Br(B! sγ)
  - Br(B_s! $\mu^+\mu^-$)

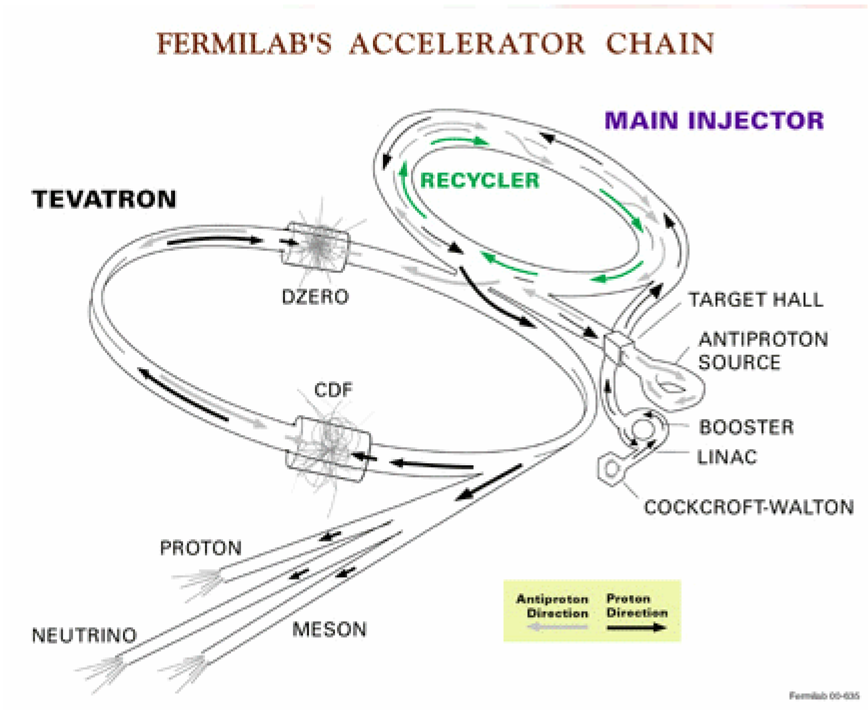
- Sophisticated MCMC guided search for high-posterior-probability parameter values

- CMSSM parameters (flat prior)
  50 GeV < m_0 < 4 TeV
  50 GeV < $m_{1/2}$ < 4 TEV
  $|A_0|$ < 7 TeV   2 < tanβ < 62

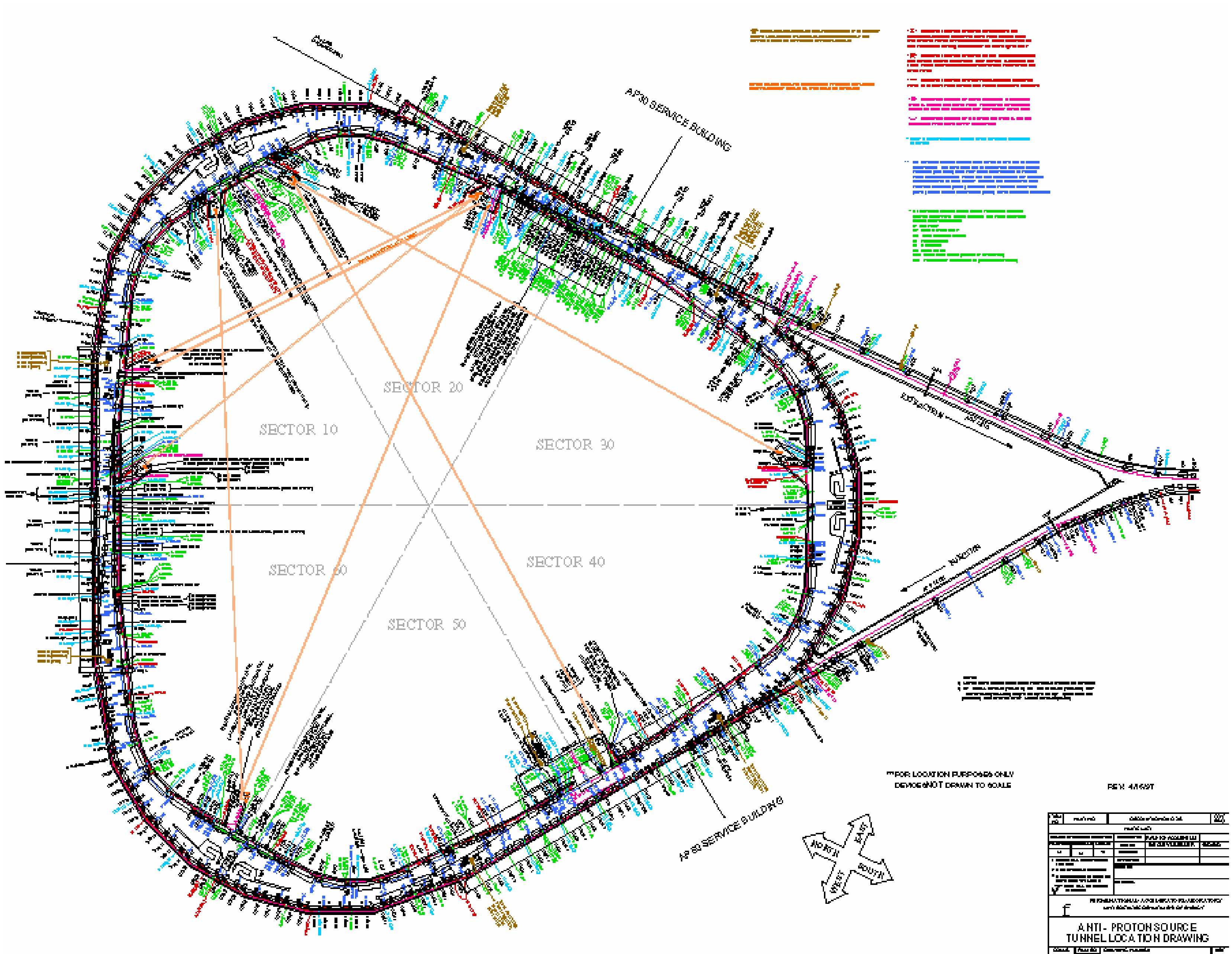
MSSM h is SM-like for these models (production, decay)

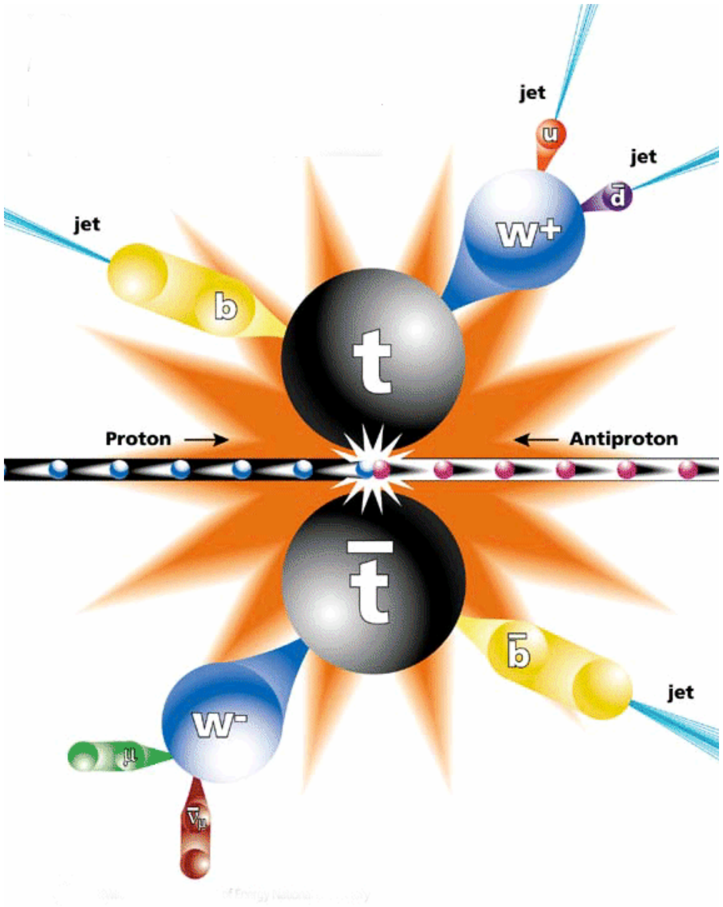
hep-ph/0611173v2
(Feb. 27, 2007)

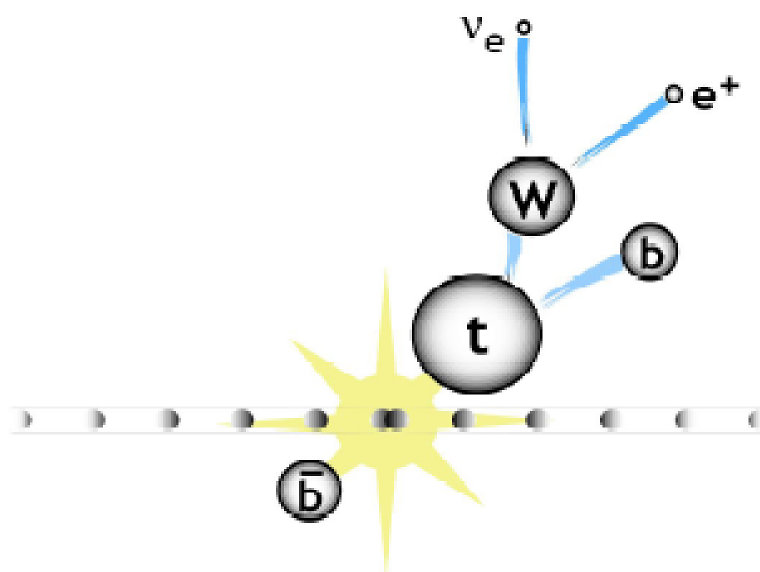



FERMILAB'S ACCELERATOR CHAIN
MAIN INJECTOR
RECYCLER
TEVATRON
DZERO
CDF
TARGET HALL
ANTIPROTON
SOURCE
BOOSTER
LINAC
COCKCROFT-WALTON
PROTON
NEUTRINO
MESON
Antiproton Direction
Proton Direction

FNAL Antiproton Debuncher and Accumulator

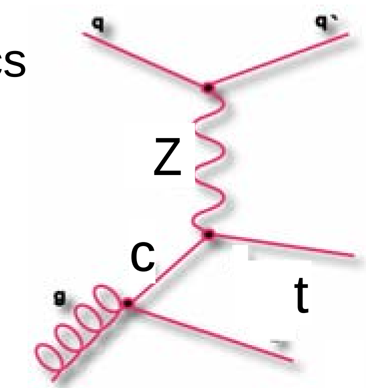



jet
u
jet
d̄
W+
jet
b
t
Proton
Antiproton
t̄
b̄
jet
W-
μ
ν̄μ

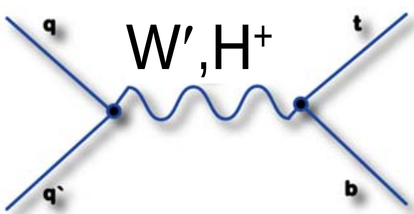

ν_e
e^+
W
b
t
b̄

Sensitivity to New Physics and WH

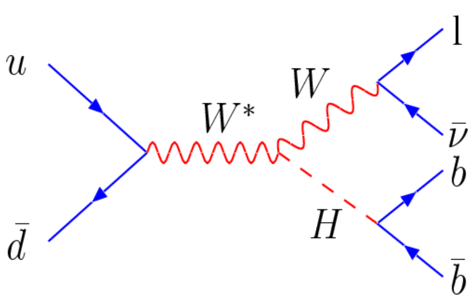
- Single top rate can be altered due to the presence of New Physics
  - t-channel signature: Flavor changing neutral currents (*t-Z/ γ/g-c* couplings)

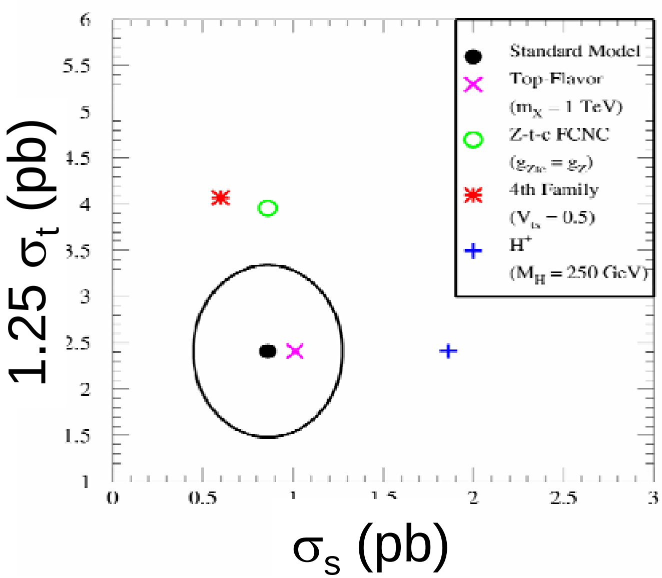


  - s-channel signature: Heavy *W′* boson, charged Higgs H^+, Kaluza Klein excited W_{KK}



- s-channel single top has the same final state as $WH \rightarrow l\nu bb$
  => benchmark for WH search!



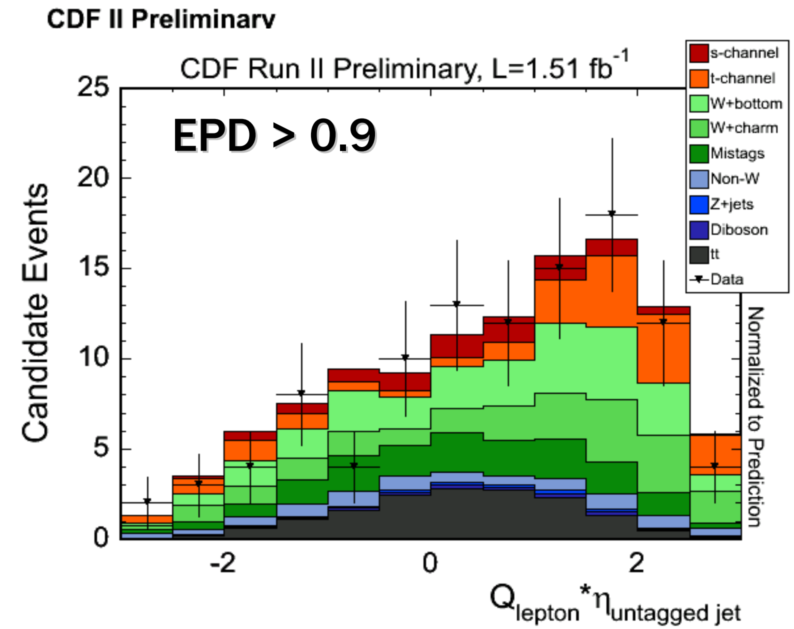


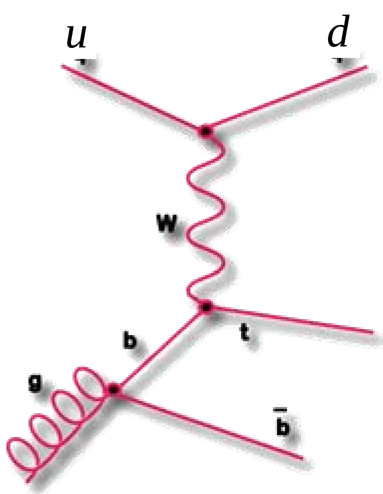
Tait, Yuan PRD63, 014018(2001)

Single Top Candidate Event

t-channel single top production has a kinematic peculiarity:

- Distinct asymmetry in Q x η distribution:
  lepton charge (Q) x pseudo-rapidity
  η=-log (tanθ/2) of untagged jet





Central Electron Candidate
Charge: -1, Eta=-0.72 MET=41.6 GeV
Jet1: Et=46.7 GeV Eta=-0.6 b-tag=1
Jet2: Et=16.6 GeV Eta=-2.9 b-tag=0
QxEta = 2.9 (t-channel signature)
EPD=0.95